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ANDESITE BRECCIA DIKES NEAR BLAIRSDEN, CALIFORNIA

BY CORDELL DURRELL

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ABSTRACT

Eight hornblende andesite breccia dikes intrude Tertiary andesite mudflows and lava of the Sierra Nevada near Blairsden, California. Similar dikes occur elsewhere in the vicinity and farther south. The dikes consist of blocks of andesite in a fine matrix rich in a clay of the montmorillonite group. The dikes are essentially the same age as their wall rocks, have the same primary mineralogy and textures, and therefore represent the same magma. They differ from the wall rocks in the kind and extent of alteration.

It is concluded that the dikes represent andesite magma injected into cold wet wall rocks and that the brecciation was due to expulsion of the volatiles on chilling and crystallization. Brecciation occurred before completion of intrusion, and breccia was erupted to the surface. The alteration occurred during and immediately after brecciation, under nonoxidizing conditions, and was due to the attack of the escaping volatiles. This is thought to have taken place at low temperature followed immediately by condensation of the vapors producing a mud matrix from the comminuted andesite and clay derived from it.

INTRODUCTION

The dikes of andesite breccia described here are exposed in a cut at mile post 312 along the Western Pacific Railroad about half way between Blairsden and Clio, Plumas County, California (Fig. 1).

Although these are not unique intrusions only one earlier notice of such a body is recorded in the literature of the Sierra Nevada. Reid (1911) briefly noted a breccia dike northeast of Marlett Peak in the Carson Range. Turner (1897) described, as doubtfully intrusive, a body of andesite breccia near Poker Flat in the Downieville

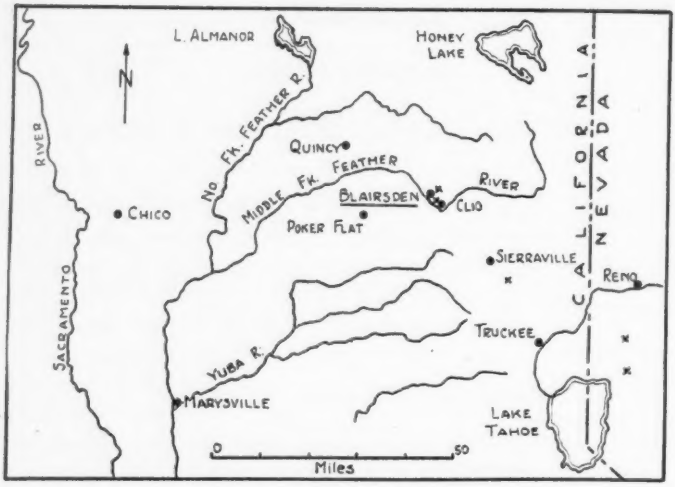


FIGURE 1.—*Index map of the northern Sierra Nevada*
Occurrences of breccia dikes are indicated by crosses

quadrangle. This, however, is clearly a downfaulted mass of bedded andesite breccia containing abundant serpentine debris and is definitely not intrusive.

Probably breccia intrusions like those near Blairsden are quite common in the summit region of the Sierra Nevada, but they are very inconspicuous except in fresh outcrops and have probably been overlooked.

GEOLOGICAL SETTING OF THE DIKES

The wall rocks of the dikes are bedded andesite breccias, possibly some subaerially deposited tuff, and an interbedded brecciated lava flow of hornblende andesite. All are of Tertiary age. These rocks constitute the visible section of a fault block in a region which was highly faulted after the eruption of andesite and a widely distributed later series of basalts (Turner, 1897). The andesitic rocks, including the dikes, are overlain unconformably by the Mohawk lake beds of late Pliocene or Pleistocene age[1], which have been only very slightly affected by faulting, and not at all by tilting (Fig. 2).

The andesitic series rests upon the bedrock series consisting of metamorphic and plutonic igneous rocks. Stream gravels, the auriferous gravels, intervene where early channels were buried by the andesitic series, but these do not occur near the breccia

[1] The author is not yet prepared to enter a controversy as to the age of the Mohawk lake beds, but he believes that they belong in the Pleistocene. The generally accepted Miocene age is based upon plant fossils from beds overlain by andesite breccia (Turner, 1895, p. 466–467) and not the Mohawk lake beds which are younger than the postandesitic faulting which created the basin in which they were deposited.

dikes. The bedrock series exposed on adjacent fault blocks consists largely of metamorphosed basic volcanic rocks and at least one thick basic sill. Metamorphosed basic tuffs and clastic sediments are also present in the vicinity but are not exhibited in near-by exposures.

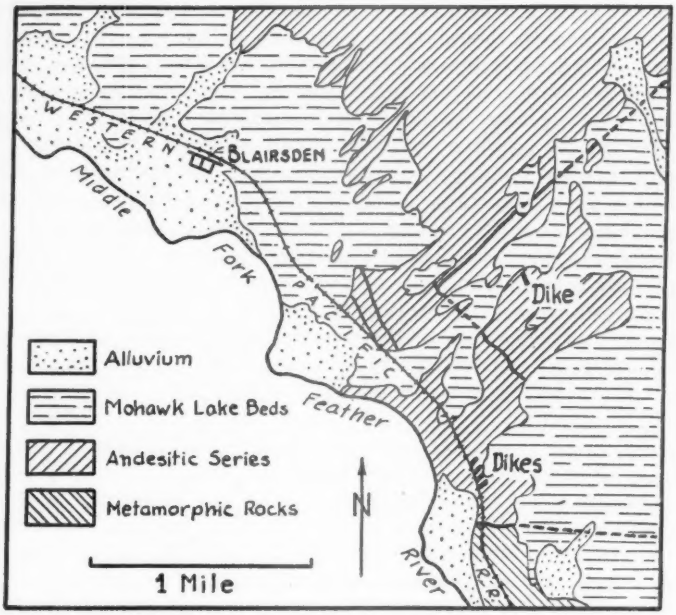


FIGURE 2.—*Geologic sketch map of the vicinity of Blairsden, California*
Showing occurrences of breccia dikes

The position of the dike exposure with respect to the top and bottom of the andesitic series is unknown. Nine hundred feet is the maximum thickness of the andesites in this vicinity, so that the thickness of the overlying cover and the depth to the underlying bedrock series must be less than that. No doubt the thickness of the cover was considerably less than the maximum.

Eight dikes are exposed in a single cut about 1000 feet long. The thickness of the several dikes and their apophyses range from a few inches to 35 feet. The contacts with the wall rocks are exceedingly sharp (Fig. 3). Where fresh the dikes are blackish green, in strong contrast to the pink, pinkish-gray, or pinkish-brown wall rocks. Weathered dike material is almost indistinguishable from the bedded material of the wall rocks. This resemblance, along with forest cover and generally incomplete exposure, makes it impossible to map the intrusive bodies except in the fresh artificial exposures. Having once seen the fresh intrusive material, however, one can recognize it in limited outcrops, but as yet the size, shape, or trend of such occurrences cannot be discovered.

STRUCTURAL CHARACTER OF THE WALL ROCKS

The andesitic rocks intruded by the breccia dikes are, on the whole, representative of that type throughout the Sierra Nevada. Many descriptions have been published, but it is worthwhile to describe them here since the details of their petrography must be compared and contrasted to that of the dikes. The following generalized description is based upon the exposures at the dike occurrences and upon a considerable amount of detailed work throughout the vicinity.

The bulk of the andesite breccia in the Sierra Nevada consists of blocks of rather dense andesite set in a matrix of fine andesitic debris. This breccia has generally been interpreted as representing consolidated mudflow material (Turner, 1896; Lindgren, 1911). Bedding can usually be observed, though many outcrops and many beds tens of feet thick are devoid of internal stratification. The blocks constitute 30 to 60 per cent of the mass and range in size from the finest particles of the matrix to individuals larger than 10 feet in diameter. Both the average and maximum sizes of blocks vary from bed to bed. Blocks other than andesite are usually sparsely present but in some areas are abundant. Many of the foreign bodies represent surface materials caught up in the flow of andesitic mud.

A minor part of the series consists of water-laid andesitic sediments ranging from silt to conglomerate. Another small portion may consist of subaerially deposited andesite tuff and tuff-breccia, though these are not easily distinguished from the mud flows.

Massive lava flows constitute a very minor fraction of the total amount of andesite spread over the Sierra Nevada, and individual flows are usually very small. Several small flows occur within a few miles of the dikes, and one is present in this outcrop.

Throughout the Blairsden area the mudflows lie almost horizontal, but tilting and drag along faults have resulted locally in dips up to 50°. The section in which the dikes are exposed (Fig. 3) may be considered to be highly disturbed.

At the north-northwest end of the section (Fig. 3) the wall rocks consist of a pink tuff overlain by a pinkish-gray to orange tuff-breccia. The exact relationships are not clear, but this material which dips 45° away from the adjacent dike may represent a section of a small subaerially deposited tuff cone.

These fragmental layers are overlain by a hornblende andesite flow in which the flow banding above the base dips 10° less steeply than the base itself. This flow extends almost two thirds the length of the outcrop and exhibits a most peculiar brecciation throughout. At no place is the flow entirely massive, and the flow banding can be seen only in irregularly spaced areas. Even here jointing is so intense that few single blocks exceed a diameter of 12 or 14 inches (Fig. 3; Pl. 1, fig. 1). Between such areas blocks of flow-banded lava are embedded in a powdery matrix of the same material. The first type of structure grades into the second by increase in the amount of matrix. The flow banding of each of the blocks embedded in fine matrix parallels that of the others which indicates that the matrix developed without rotation or jostling of the larger unbroken fragments. This kind of material grades imperceptibly by increase in the amount of matrix and decrease of the size of blocks into material indistinguishable from the mudflows, except that the larger blocks show flow

banding, a structure which is present but not common among the blocks of the true mudflow material. The above types of material are irregularly intermixed in the northern two thirds of the section.

The wall rock material of the southerly third of the section is bedded and includes a layer of fine pink andesitic detritus, 5 to 8 feet thick, which may be subaerially deposited tuff. The bed above the fine pink layer is typical mudflow material. The bed beneath the pink tuff contains flow-banded blocks identical to the brecciated flow, but it is otherwise like the mudflows. One small fault block is clearly a part of the brecciated flow, and since the normal faults which bound this block have very small displacements it appears that the horizon beneath the pink tuff is in reality a highly brecciated part of the lava flow structurally identical to the mudflows.

The brecciation of the lava flow is obviously not tectonic as there is no slickensiding or any systematic disposition of material brecciated to different degrees. Furthermore, the persistence in attitude of flow banding in widely spaced blocks could hardly have survived a tectonic disturbance of such magnitude as to pulverize the intervening massive andesite. The only apparent explanation is that this structure is due to igneous processes, probably the violent escape of water or water vapor in the later stages of consolidation of the magma. Such a process could result in a breccia of blocks of various sizes and shapes set in a pulverized matrix. This concept will be developed further in connection with the dikes.

The andesitic series constitutes a relatively weak and porous body, and at the time of deposition and thereafter it was saturated with water and at ordinary temperatures. The interbedded brecciated lava flow must also have been cold and wet shortly after extrusion, because it was immediately buried by water-saturated mudflows.

PETROGRAPHY OF THE WALL ROCKS

BRECCIATED LAVA FLOW

Macroscopically this is a color-banded hornblende andesite with alternating dark-gray and pink or pinkish-gray bands marking the flow planes. Phenocrysts of basaltic hornblende and plagioclase up to 3 millimeters long constitute 30 to 40 per cent of the rock. Their larger dimensions lie in the flow planes.

Microscopically, euhedral phenocrysts of basaltic hornblende, andesine-labradorite, and hypersthene are set in a trachytic groundmass of plagioclase laths, needles of hypersthene, magnetite granules, and a mesostasis of glass and tridymite.

The typical basaltic hornblende is partially to completely resorbed and altered to magnetite and brown iron oxides. The hypersthene is fresh and euhedral both as phenocrysts and in the groundmass.

The groundmass is rich in andesine microlites in trachytic arrangement. There are two phases in the groundmass, however, which are arranged in streaks or patches, and which constitute a part of the flow structure. The dark-gray parts of the rock consist of abundant plagioclase laths with minor hypersthene and magnetite set in a sparse paste of glass which has a relief a little lower than balsam. The pinkish phase contains far fewer plagioclase laths, and the glass is replaced by what is certainly mainly tridymite, but which may be in part cristobalite. The pinkish phase tends

to be microvesicular with euhedral crystals of the silica mineral lining the cavities. Glass is present though scarce.

A few larger euhedral crystals of magnetite and occasional stubby apatite crystals, dark with tiny inclusions, are also present.

MUDFLOW BRECCIAS

Hypersthene andesite and hornblende-hypersthene andesite are the dominant rock types among the blocks of the mudflows, and both may carry augite in addition. Rocks with augite or hornblende as the sole characterizing accessory are rare, as is the combination augite and hornblende. Blocks of hornblende-hypersthene-augite-olivine andesite and olivine basalt are present but rare. Mica andesites were reported by Turner (1895, p. 487) within a few miles, but the writer has not seen them. Systematic distribution of blocks is not discernible, and a great variety of rock types may be found in any one outcrop.

The andesites are generally dense, but some of them are microvesicular. The olivine basalts are coarsely vesicular. The blocks are dominantly angular, often with concave surfaces and slightly rounded edges, but the rounding does not seem to be due to atrition. Breadcrust surfaces are lacking, and, except for surface weathering in the outcrop, there are no differences between the outer and inner portions of the blocks, either microscopically or macroscopically.

The following description applies to the andesite blocks in general, as well as to the previously described brecciated lava flow, but not to the occasional olivine basalts. The latter rocks are not important to the problem, and no further mention will be made of them.

The plagioclase phenocrysts show great complication in history through complex zoning and other textural features similar in many respects to those described by Larsen (1938) from the andesites of the San Juan Mountains of Colorado. Several different types of phenocrysts often occur in the same thin section. The range of composition is from An_{70} to An_{30}, and this range often occurs within a single crystal. Although an average composition for the phenocrysts cannot be determined accurately as yet, it perhaps lies between An_{60} and An_{65}.

The amphibole is mostly the deep-brown basaltic hornblende, though green hornblende does occur. The former shows the characteristic pleochroism from yellow to deep brown, high double refraction, and small extinction angle. Both types always show more or less alteration to magnetite, though the basaltic hornblende yielded mostly red oxides. Alteration to an aggregate of hypersthene, augite, plagioclase, and granular magnetite has also taken place,—apparently earlier than the principal development of magnetite or red oxides. The hornblende crystals range from very small up to more than half an inch in length, but they seem to be always phenocrystic as they are not found in intimate relationship to plagioclase in the groundmass as is hypersthene.

Hypersthene, generally the most abundant ferro-magnesian mineral, occurs as fresh, clear, euhedral prisms and as tiny rods and granules in the groundmass. Some of it is altered around the edges to red iron oxides, and a little is altered to serpentine.

Augite usually occurs as large scattered crystals, clear and unaltered. A few rocks contain granular augite in the groundmass along with hypersthene.

Olivine is rare and occurs only as sporadic phenocrysts. It has not been found in the groundmass.

Magnetite is present as relatively large euhedral crystals, as tiny granules in the groundmass, and as an alteration product of hornblende.

Apatite is present in nearly every section and is quite abundant in many. Its occurrence as short prisms, usually dark with a central cloud of black inclusions, is persistent and characteristic.

Tridymite, present in nearly all sections, occurs characteristically in clots with many crystals idiomorphic toward microvesicles. Cristobalite has not been identified.

Phenocrysts constitute from 20 to 75 per cent of the rock, with a maximum frequency between 45 and 60 per cent.

The groundmasses of these rocks are very fine-grained, mostly hyalopilitic, some pilotaxitic. The groundmass microlites have a trachytic arrangement in some specimens, but in most there is no evident orientation of either phenocrysts or groundmass constituents. A colorless or light-brown usually clear glass is present in small amount in nearly all sections.

A conspicuous feature of these rocks is the presence of large numbers of glomeroporphyritic clots or segregations composed of plagioclase, magnetite, augite, or hypersthene, or all four minerals. These clots are so abundant that nearly all slides show at least one, and some contain several. Large highly resorbed remnants of hornblende have been found at the centers of a few. The origin of these clots is not understood, and, in fact, they may have formed in several ways. The presence of resorbed hornblende crystals suggests that they may be derived by the alteration of that mineral, particularly as it alters to plagioclase and hypersthene. On the other hand many of the clots appear to be hypautomorphic in texture as though they were xenoliths of hypersthene diorite, while the textures of others suggest xenoliths of plagioclase-pyroxene hornfelses. Some may be truly clots of phenocrysts.

The alterations of these rocks, while not extensive, are in general due to oxidation. These include the change of green to basaltic hornblende and the formation of magnetite and red iron oxides from hornblende, and red iron oxides from magnetite and hypersthene. Frequently there is some alteration of the glass of the groundmass, in part to a greenish-brown chloritic substance and in part to a clay mineral and iron oxide. In microvesicular rocks this alteration is most intense around the vesicles, pointing to the residual mineralizers as the agent. The reaction of hornblende to form plagioclase and pyroxene seems to have been intratelluric, while the other alterations probably all occurred during or immediately following eruption to the surface.

The matrix of the mud flow breccia is composed of comminuted andesite. Angular fragments of plagioclase, hornblende, pyroxenes, tridymite, glass, and groundmass are dominant. There is only a very little calcite. These fragmental materials are bound together by a relatively small amount of a clay mineral of the montmorillonite group. Grain studies indicate that the clay is a direct alteration product of glass. The prevailing color of the matrix is gray, but locally it is pink, red, or purple owing to more intense oxidation.

There is no natural division between blocks and matrix as fragments range in size from the largest blocks down to a diameter of less than 1 micron.

DIKES

STRUCTUAL FEATURES

The exact form of these intrusive bodies is unknown as exposures do not permit tracing them away from the cut in which they are so well shown. Although it is entirely possible that they are much more irregular than is supposed, nevertheless the term dike seems applicable, for, as far as can be determined, the walls are essentially parallel.

Some of the exposed walls of the dikes are straight, while others are very irregular. Dike 7[2] (Pl. 1, fig. 2) has a very straight contact on the north (left) side, and a highly irregular one on the south. Contacts with the wall rocks of all the dikes are exceedingly sharp. The dike material separates easily from the wall, and a feeble slickensiding is generally present. Within the dikes and parallel to their margins are planes of shearing or joints (Fig. 3; Pl. 1, figs. 2, 3; dikes 6, 7) at distances from a few inches to more than 1 foot from the contact surface. Along some margins several parallel joints occur. In dike 6 such joints separate the main body of the dike from apophyses on either side. Clearly these joints were developed by movement of the central part of the dike after material had been injected into the apophyses or had become consolidated along the walls.

The eight principal dikes send off numerous apophyses, best seen in connection with dike 6 (Fig. 3). A detail of the small injections of the lower left-hand portion of this body is shown in Figure 3 of Plate 1. All the apophyses, no matter how narrow (one is less than half an inch wide), have exactly the same character as the larger bodies. Half-inch wide apophyses contain fragments up to one-fourth inch in diameter. Blocks, in the strict sense—that is, with a diameter greater than 32 millimeters (Wentworth and Williams, 1932)—constitute 50 to 60 per cent of the dike filling. Most of the material, perhaps as much as 90 per cent in places, is composed of obvious fragments of andesite, the remainder being megascopically fine. There is, however, considerable variation, for close to the contacts the proportion is almost reversed with fine material constituting 70 to 80 per cent of the bulk.

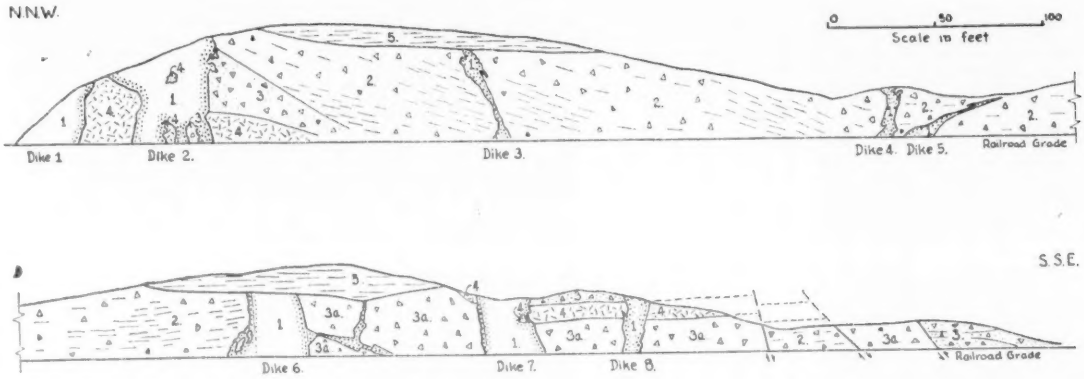
Exclusive of xenolithic fragments, the largest blocks are about 14 inches in diameter, but the commonest size is from 4 to 6 inches. Dikes 7 and 8 (Pl. 1, figs. 2, 4) show a notable gradation horizontally with respect to the size of blocks which are largest at the center and progressively smaller toward the dike margins. Undoubtedly this was due to some sorting action during intrusion.

The blocks are all roughly equidimensional and angular, although some show a slight rounding. Many have concave surfaces like the blocks of the mudflows.

Xenoliths of the wall rocks are rare, though dikes 1 and 7 (Fig. 3; Pl. 1, fig. 2) contain several large xenoliths obviously derived from the immediately adjacent walls, as well as several individual blocks from the mudflows. These are conspicuous in the field because of their color and the presence of basaltic hornblende.

Dike 1, at the extreme northwest end of the section (Fig. 3), is unique in that it consists of a brecciated mass of hornblende-hypersthene andesite which lacks almost entirely a matrix comparable to that of the other dikes. Complete shattering with-

[2] For convenience in description the eight dikes are numbered on Figure 3, consecutively from north-northwest to south-southeast.



1. Breccia dikes.
2. Brecciated lava flow.
3. Mud flow breccia, bedded.
3a Breccia, probably same as 2, but indistinguishable from 3.
4. Fine pink ash, subaerial tuff or mud flow.
5. Mohawk Lake Beds.

FIGURE 3.—*Sketch of the cliff face*

Showing eight andesite breccia dikes and their wall rocks. Flow banding in the brecciated lava flow is represented diagrammatically by short lines.

out important relative displacement of the fragments has occurred. The individual blocks are mostly less than 1 inch in diameter.

That these dikes are intrusive bodies is obvious from the contact relationships. The presence of thin apophyses, and the ramifying character of dike 6 permits no other interpretation. It is equally clear that the material of dikes 2 to 8 was breccia when intrusion occurred for even the smallest apophyses consist of breccia structurally identical with that of the larger bodies.

PETROGRAPHY

The blackish-green dikes contrast strongly with the pink, pinkish-gray, and brown enclosing lava flow and mudflows, and this is directly due to differences in alterations which each has undergone. These colors are only slightly modified by weathering. The freshest of the dikes, however, is a blue gray rather than green; but undoubtedly weathering has not caused the alterations to be described.

The blocks of the breccia dikes vary in mineralogy and texture, but to a lesser extent than do those in a single outcrop of mudflow breccia. Several varieties of andesite can be found in each dike except dike 1, but by far the greatest number of blocks are hornblende-hypersthene andesite. This is followed in abundance by hypersthene andesite and augite-hornblende-hypersthene andesite.

The primary mineralogy and textures of these rocks are identical with those of the blocks of the mudflows. The plagioclase phenocrysts show the same variations in textural features, composition, and zoning. Hornblende is always phenocrystic and is commonly altered to magnetite and pyroxene around the edges. Hypersthene, though usually altered, occurs both as euhedral phenocrysts and in the groundmass. Augite, also usually altered, has been identified only as phenocrysts, but it might also have been present in the groundmass. Magnetite occurs both as large euhedral crystals and as granules in the groundmass. Clouded large stubby prisms of apatite, identical with that in the blocks of the mudflows, are present in nearly all slides.

Phenocrysts constitute 50 to 60 per cent of the rock and indicate advanced crystallization before intrusion.

The groundmass textures were originally the same as those of the mudflow blocks, but more alteration has occurred. Glass is rare, being mostly altered to chlorite and a clay of the montmorillonite group. As in the mudflows trachytic arrangement of the groundmass microlites is rare. The prevalent sizes and habits of both the phenocrysts and groundmass minerals are identical in the two sets of rocks.

Nearly every variety of andesite among the blocks of the dikes can be matched texturally and mineralogically with specimens from the mudflows.

There are also some important points of difference between the two sets of rocks. Glomeroporphyritic clots are much less common in blocks from the dikes. Tridymite is lacking, and its place is taken by quartz which has the same general occurrence—that is, in irregular patches scattered throughout the groundmass. Each patch is a granular aggregate, and sporadic wedge-shaped grains among these suggest that at least some of the quartz may be pseudomorphic after tridymite.

Of great importance is the fact that the hornblende of the dike rocks is exclusively green. There is usually a slight brownish tint, but the double refraction and the extinction angle are normal.

FIGURE 1. DIKE 2 ON LEFT, AND BRECCIATED LAVA FLOW OVERLYING TUFF-BRECCIA (LIGHT COLORED)
Areas of more massive flow-banded lava separated by intensely brecciated lava are well shown. Flow banding is inclined from left to right.

FIGURE 2. DIKE 7
Showing sharp contacts with wall rocks, a relatively straight contact on left and an irregular contact on right. Gradation of blocks from coarse at the center to fine at the margins, and a prominent shear line parallel to the left margin are evident. Xenolith of adjacent wall rock appears along the right contact separated from the wall by less than 6 inches of intrusive breccia. Width of dike at the center of picture is 25 feet.

FIGURE 3. APOPHYSES OF DIKE 6
Shear fracture parallel to the dike wall may be seen above the apophyses. Width of picture is about 22 feet.

FIGURE 4. DIKE 8
Showing pronounced gradation in size of blocks from center to margin and relatively straight contacts with bedded wall rocks. Dike is 8 feet wide at narrowest point.

ANDESITE BRECCIA DIKES

Alteration in the dike rocks is more extensive and different from that in the mudflows. The hornblende, as noted earlier, is generally altered to magnetite around the edges, but the rims are narrower than in the mudflow blocks. Red iron oxides do not occur. Other alteration products of the hornblende are chlorite (usually penninite), calcite, leucoxene, epidote, and a montmorillonite-type clay.

Plagioclase is commonly altered to a clay mineral along cracks. Calcite and epidote, derived from plagioclase, are present in many sections, and albite in irregular streaks and patches is present in the plagioclase of a few blocks. This latter alteration seems not to involve the formation of new albite since the albitized crystals are porous, and concurrently formed idiomorphic epidote crystals extend into the cavities. Apparently the albite is residual from the alteration of the anorthite.

Some hypersthene is fresh, but most is altered to chlorite, serpentine, or a chloritic mineral close to bowlingite. With rare exceptions, the groundmass hypersthene is completely altered.

Chloritic minerals also result from the alteration of glass, and it is often impossible to distinguish this from chlorite after the groundmass hypersthene.

A clay mineral of the montmorillonite type—an alteration product of plagioclase, hornblende, and glass—occurs in nearly all sections and is abundant in some. Due to the fine-grained character of this substance, stains were used for identification both on hand specimens and thin sections. Specific identification has not been possible, but it responds to the stain tests of the montmorillonite group (Faust, 1940).

The character of the alteration is essentially the same in all blocks, yet there are slight differences in the extent and in kind. Epidote, for example, is found in only about half the blocks, and residual albite has been found in only a few blocks. These differences show that alteration preceded injection of the breccia to its final resting place.

In the dikes are a few blocks mineralogically like but texturally unlike the blocks just described. They are coarse-grained dioritic rocks, closely resembling some of the coarse-grained clots which are so abundant in the blocks of the mudflows. They are also similar to certain coarse-grained metamorphosed intrusives which occur in the bedrock series nearby so that it is impossible to decide to which group they belong. They seem not to have any significant bearing on the problem of the origin of the dikes.

Only one block has been found in the dikes which is without doubt a xenolith of the bedrock series. This small specimen is a metamorphosed rhyolite identical with that several miles to the southwest which was mapped by Turner (1897) as quartz porphyry.

The few xenolithic blocks from the mudflows found in the dikes show all the characteristics of the mudflow materials with no trace of the alteration characteristic of the cognate blocks of the dikes. This is also true of the larger xenoliths of the wall rock which were obviously torn from the immediately adjacent walls. Indications are that the dike material was altered before injection to the present position. There is likewise no alteration in the wall rocks adjacent to the dikes which could be attributed to them.

The matrix of the dikes is texturally like that of the mudflows. It consists of angular fragments of all the minerals found in the blocks set in a fine paste consisting

in large part of a clay mineral of the montmorillonite group. The clay content of the matrix near the margins of the dikes is higher than at the center. Abundant chlorite in the matrix gives it a dark-green color.

Several blocks from the dikes are themselves breccias in which the blocks and matrix exhibit the characteristics described above in single thin sections. These are evidently portions of the brecciated mass which were strong enough to resist disintegration during intrusion.

Dike 1 (Fig. 3) is uniform in composition but is comparable to blocks of the other dikes. The green hornblende is partly chloritized. Hypersthene is altered to bowlingite, and chlorite is abundant in the groundmass. Clay occurs in small quantities in the groundmass, in the central parts of the plagioclase phenocrysts, and is in part an alteration product of hornblende.

The fracturing in this dike is so closely spaced that it is nearly impossible to obtain a hand specimen, and all the fractures are filled with clay. Broken phenocrysts may be matched across many of the joints showing that no relative displacement has occurred. Along other fractures there has been movement, and here and there between the larger fractured but otherwise undisturbed units are pockets and veinlike masses of a matrix exactly like that of the other dikes. Staining shows that clay is scarce in the groundmass of even the small fragments away from the veinlets, but that the clay of the veinlets and matrix is derived from the groundmass feldspar and original glass.

The absence of any relative displacement along a large proportion of the fracture surfaces and the mineralogic and textural homogeneity of dike 1 show clearly that the brecciation occurred essentially in place and is not due in any important degree to attrition. Further movement would have entirely disrupted the continuity so clearly seen across the clay-filled veinlets, hence this dike must have been injected to, or almost to, its present position as magma. No doubt further movement would have produced from this body a dike exactly like the others, so that this is clearly an arrested state of the breakup which caused the more completely brecciated bodies.

The essential contemporaneity of alteration and brecciation is obvious. Alteration could not have preceded brecciation for this dike was intruded as magma, and the course of alteration was largely controlled by the breccia structure. Alteration could not have followed brecciation with any appreciable lapse of time as it is identical in character with that of the other dikes wherein it occurred before the completion of injection.

The alteration agent was clearly of internal origin, because of the total absence of any similar influence upon the wall rocks in contrast to its all-pervasive character in the dike. This agrees with evidence from the other dikes where brecciation and alteration occurred before the completion of injection.

Undoubtedly, the mudflow material, the brecciated lava flow interbedded with the mudflows, and the intrusive breccia dikes represent the same magma. This is clear from the identity of textures and mineralogy, excepting alteration products. It is therefore concluded that the dikes are essentially contemporaneous with their wall rocks, and that they were injected during the epoch of andesitic eruption. Thus, they are older than the post-andesite olivine basalts which occur elsewhere in the vicinity.

The dikes differ markedly from the surficial rocks in alteration products. The change of green to basaltic hornblende and the development of red iron oxides from hornblende, pyroxenes, and magnetite indicate oxidation which is to be expected in extrusive materials. In the intrusive rocks oxidation products are lacking, and chlorite, epidote, bowlingite, serpentine, and calcite are widespread. In both groups hornblende is partly altered to magnetite and hypersthene, and this is therefore to be considered an earlier change, probably truly magmatic.

OTHER OCCURRENCES OF BRECCIA DIKES AND SIMILAR MATERIALS

In addition to the occurrence mentioned by Reid (1911), several andesite breccia dikes in the Carson Range are exposed along the Mount Rose Road, Nevada, between Lake Tahoe and Reno Hot Springs, about 1 mile southeast of the Galena Creek Public Camp. Several others crop out in road cuts on the highway between Sierraville and Truckee, California, 7 miles southeast of Sierraville. Neither occurrence has been studied in detail, but they appear to be identical with the dikes under discussion. The wall rocks at both places are andesite mudflow breccias and conglomerates.

There are also other occurrences in the Blairsden quadrangle. One large dike is exposed on the highway between Blairsden and Portola in the NE$\frac{1}{4}$ sec. 13, about 1 mile northeast of the eight dikes being described. At this locality the wall rocks are also andesite mudflow breccias, and the dike walls are very irregular. The body rapidly widens upward, as seen in a cliff about 40 feet high, so that it looks like a section of a funnel. This section is probably very near the point where the dike broke through to the surface.

In this same cliff section are large rounded masses of dark-green breccia entirely enclosed in the pinkish-gray mudflow materials, and these are identical to the breccia dikes. Similar masses of dark-green breccia identical with the dikes but enclosed in mudflows are notably abundant in the railroad cuts about 3 miles farther east, near the west portal of the tunnel in the NW$\frac{1}{4}$ sec. 20, R. 13 E., T. 22 N. Here several of the masses have a diameter of 12 feet.

Such enclosed bodies could only have originated by the extrusion of breccia to the surface during the deposition of andesite mudflows, and these occurrences thereby not only demonstrate the fact of extrusion of material brecciated in depth but show, as well, the essential contemporaneity of the dikes and their wall rocks.

ORIGIN OF THE BRECCIA DIKES

Thus far the dikes have been considered to be of intrusive igneous origin, and this is undoubtedly true. Breccias may originate in many ways, however, and it seems worthwhile to point out the inapplicability of other modes of origin.

That the breccia dikes are not of any direct sedimentary origin is obvious because of their transgressive character. That they were not formed by the reinjection of mudflow material, in the manner of sandstone and conglomerate dikes, is indicated by the fact that the hornblende of the dikes is green whereas that of the mudflows is basaltic. The possibility of the differences between the dikes and the wall rocks being due to alteration subsequent to injection in this manner is untenable, since the regeneration of green from basaltic hornblende is unknown in nature. The fact that wall-rock

xenoliths in the dikes do contain basaltic hornblende does not indicate this to have occurred or to be possible.

For exactly these same reasons it is clear that the dikes were not formed by localized brecciation of mudflow material by faulting or by subsequent alteration. Faults are abundant in this region, and several small faults occur in this section. They have been carefully studied over a large area, and in no case has brecciation by faulting produced structures like the dikes.

Brecciation of massive dikes by faulting seems highly unlikely since it would require the confinement of brecciation to thin but massive and strong bodies surrounded by weak, undisturbed wall rocks. The confinement of subsequent alteration to those zones would be another unlikely coincidence. The fact of injection of thin apophyses of previously altered material reduces the assumption to absurdity.

Fairbairn and Robson (1942) have shown that intrusive breccias may originate by the passage of aqueous solutions at elevated temperatures through pre-existing fractures. The breccia fragments were torn from the walls, and a fine mobile matrix produced by the action of the fluids. The matrix was able to transport large blocks upward. This process has much in common with that to be developed for the Blairsden dikes. The origin cannot be the same, however, because the dike filling was not derived from the walls as is shown by the differences in the hornblende.

It might be assumed in this connection, and also in connection with simple reinjection in the form of clastic dikes, that the green hornblende-bearing rock was simply derived from a deeper unexposed body of mudflow material which had these characteristics. This is highly improbable as the complete section of the andesitic series is exposed in many places near by, and no such material is known to occur.

None of the possibilities enumerated above can account for the structure of dike 1. This dike represents a magmatic injection brecciated and altered in place, and it would be absurd to assume a special origin for this particular body which so clearly shows the brecciation in an arrested state.

Fairbairn's idea of a wet and mobile matrix, however, would apply to the Blairsden dikes, and the author developed this concept independently of Fairbairn's work. The essential difference is that, in the case he described, the solutions originated outside the brecciated body, whereas in the Blairsden dikes the solutions originated within the intrusive mass.

The dikes are injected bodies of igneous origin, they represent the same magma as the mudflows and lava flows into which they were intruded, and they are essentially contemporaneous with their wall rocks. They cannot be thought of as representing former wall-rock material for the green hornblende positively indicates a direct magmatic origin. They have never suffered oxidation as have the surficial wall rocks, and the structures of dike 1 show that it was injected to, or very nearly to, its present position as magma.

BRECCIATION OF THE DIKES

The igneous origin of the dikes being clearly established there remains the problem of the cause and mechanism of brecciation. The following preliminary conclusions which have a bearing upon this question are summarized from the foregoing sections:

(1) The dikes are of igneous origin.

(2) The dike magma was in an advance state of crystallization at the time of intrusion as is indicated by the abundance of phenocrysts.
(3) Intrusion occurred to a shallow level.
(4) The wall rocks were relatively weak.
(5) The wall rocks were cold and saturated with water.
(6) Dike 1 was intruded to, or nearly to, its present position as magma.
(7) Dike 1 was brecciated essentially in place.
(8) Comminution in dike 1 was not due in any important degree to movement.
(9) Dikes 2 to 8 were injected after solidification and brecciation.
(10) Elsewhere, breccia was extruded during the period of deposition of the mudflows.
(11) Alteration accompanied brecciation in dike 1.
(12) Alteration preceded final injection in dikes 2 to 8.
(13) The agencies of alteration were of internal origin.

Intrusive breccias of many ages have been long known at many places throughout the world. The tuff-breccia necks of the Navajo volcanic fields described by Gregory (1917) and by Williams (1936) are well known, as are the irregular tuff-breccia pipes of Eastern Fife described by Geikie (1902). The Blairsden dikes closely resemble some of the dikelike bodies described in Geikie's work. Little significance is to be attached to another description of such rocks, but further implications to be drawn from the present study may be important.

As in the case of earlier-described intrusive breccias, the brecciation is clearly an igneous process. Here, however, the brecciation was accompanied by extensive alteration, producing among other things the clay of the matrix. In view of the close association of brecciation and alteration both seemingly resulted from the activities of the escaping fugitive constituents of the magma.

Brecciation as an igneous process may, however, come about in several ways. If the brecciation were due solely to continued magmatic pressure from below upon a rapidly congealing magma, one would expect results similar to brecciation by faulting. Near the surface, with weak wall rocks, it seems very unlikely that pulverization of massive rock could have occurred without disturbing the wall rocks. However, in this area, the wall rocks are undisturbed particularly in the case of dike 1 which was brecciated at the present visible level.

Brecciation due simply to thermal contraction on cooling is also unlikely. Since the wall rocks are surficial and were undoubtedly cold and saturated with water, chilling must certainly have been a factor. However, the fugitive constituents of the magma which produced the alteration accompanying and following the brecciation must also have played a part, hence chilling cannot have been the sole factor.

The dike magma which was in an advanced stage of crystallization must have been rapidly cooled on being injected in small bodies into cold and wet wall rocks at a shallow level. Rapid chilling caused further crystallization and concentration of the volatile constituents in the ever-diminishing liquid residue. Thereby, pressures in excess of the confining pressure may develop. In the case of dikes 2 to 8 the magma continued to rise after brecciation and therefore probably during brecciation, causing rapid lowering of the external pressure. When rapid cooling and lowering of external pressure occur, violent escape of the volatiles is expected. That this should cause

disruption of the nearly completely crystallized magma is clearly indicated by the structures of dike 1.

Brecciation as the result of expulsion of volatiles is not a novel idea and is in part the mechanism of the volcanic explosion. Morey (1922) and Goranson (1938) describe this process as due to the rapid rise of vapor pressure of the volatiles on crystallization of nonvolatile phases. Thus, Day and Allen (1925) for Lassen Peak and Shepherd and Merwin (1927) for the 1902 eruption of Mt. Pelee explain the explosive character of volcanic eruption.

The Blairsden breccia dikes differ, however, from the products of volcanic explosions in being nonvesicular. Shepherd and Merwin (1927) stress the importance of vesiculation in the production of the volcanic explosion; nevertheless, the absence of such structures need not require the abandonment of the idea for the present case. Here there is no evidence of the usual large-scale explosion. We are dealing with the fracturing and pulverization of small bodies in such a way as to leave the walls undisturbed. The confining pressure was certainly low. The very rapid lowering of temperature may have caused the magma to have consolidated too rapidly to permit vesiculation.

That the confining pressure was low is known from the thickness of the andesitic series. The present level of exposure of the dikes could not have been overlain by more than 900 feet of weak, water-saturated mudflow material, and the actual cover may have been much less, for the base of the andesitic series is not exposed within the fault block in question.

The temperature of the magma is of course unknown, but an upper limit for the later stages of consolidation is indicated by the character of the hornblende. Green hornblende is changed to basaltic hornblende at about 800°C. (Barnes, 1930), so that it seems reasonable to assume that the absence of basaltic hornblende in the dike rocks indicates that they were never above that temperature after the crystallization of the hornblende phenocrysts. The maximum possible temperature was then several hundred degrees less than observed temperatures at volcanic vents which are in excess of 1000°C. (Daly, 1933). The actual temperature at the time of brecciation may have been far lower than 800°C. for the hornblende is entirely phenocrystic, and a considerable period of crystallization following the hornblende and severe chilling on intrusion are certain. Possibly the temperature was as low as 500°C. although there is no obvious way of establishing such a value. Low temperature is evidenced by the total absence of any contact metamorphic effect on the walls including those of dike 1.

The complete confinement of the characteristic alteration to the dikes has already been taken to mean that the altering agent was of internal origin. That agent was the volatile constituents liberated as outlined above. Paulopost alteration or the attack on pyrogenic minerals by the residual mineralizers is a generally recognized phenomenon, and calcite, chlorite, and epidote are frequently formed in that manner. The abundant clay mineral of the montmorillonite group has a further importance, for its presence in a wet matrix would lubricate the breccia, thus greatly facilitating injection.

The volatiles liberated at the time of brecciation would be expected to exist in the vapor state, and no very conclusive evidence can be brought to bear on their conden-

sation. The boiling temperature of pure water under a hydrostatic head of 900 feet, which is the probable maximum value for dike 1, is about 230°C. The temperature drop to this value, required for condensation, would probably be between 200°C. and 500°C. These values are little more than guesses, but they do give a rough idea of the values required. Cooling of the liberated vapors must have occurred, however, due to expansion and the presence of cold walls. In view of the small size of the intrusive bodies and the condition of the wall rocks, cooling sufficient to cause condensation shortly after or even during brecciation seems not unlikely.

Epidote, calcite, chlorite, and clay are typical hydrothermal minerals, often found in the altered wall rocks of hydrothermal mineral deposits. The occurrence of this assemblage under many situations would be accepted as evidence of the existence of hydrothermal liquids in spite of the total lack of positive evidence of actual temperatures and the physical state of the fluids. Epidote, chlorite, and calcite, while generally of low-temperature origin, furnish no positive data, since they form under a broad range of conditions. The presence of clay, however, is more positive indication of low temperature and probable liquid state of the fluids.

The results of much experimentation on the synthesis of the clay minerals have been published in recent years. (For summary, *see* Morey and Ingerson, 1937.) While the limiting conditions for the formation of clays cannot be said to be determined, it is quite clear that low-temperature hydrothermal conditions are indicated. This agrees with the general geological knowledge that the clay minerals result usually from the weathering of silicates at ordinary temperatures and from alteration under epithermal conditions. In view of the high water content of the montmorillonite clays and their usual origin at surface temperatures and pressures, it is probable that the fluids in the Blairsden dikes were liquid,—at least very shortly after brecciation, during the formation of the clay.

Certainly the geological evidence points to this conclusion. The injection of thin apophyses indicates a high mobility of the breccia due to a wet matrix rich in clay, and extrusion of breccia from other similar dikes would also seem to require a liquid matrix. The restriction of the alteration to the dikes, and the lack of it in the xenoliths of mudflow material becomes more readily understandable if the fluid were liquid rather than a highly permeating gas. The breccia, as intruded, is believed to have been a highly mobile mass of large and small blocks of andesite in a matrix of comminuted andesite and alteration products, wet with liquids liberated from the magma.

The development of a mobile mud matrix may seem to require a very high water content in the magma. Sufficient water must be assumed to produce the results required by other evidence. However, the mud matrix represents only part of the magmatic substance from which water was concentrated by crystallization. The increase of water in the mud was probably two or three times the original water content of the magma.

The process of brecciation outlined above would depend upon many factors including the composition of the magma, its degree of crystallization when chilled, the rapidity of injection, and the dimensions of the body involved. If such a process has operated at shallow depths, as seems to have been the case, then it could conceivably operate upon extruded bodies. While it has not been the intent to discuss this possi-

bility in full, the process developed here seems to explain adequately the structures observed in the brecciated lava flow which forms a part of the wall rocks of the dikes. Here the autobrecciation certainly occurred after extrusion.

POSSIBLE ORGIN OF THE ANDESITE MUDFLOWS

The fact that andesite breccia with a mud matrix has been intruded to form these dikes, and the fact that identical material has been extruded in the immediate vicinity indicate that surface mudflows may originate in this way. No adequate sources of the andesite mudflows so widely spread over the Sierra Nevada have previously been found, and it seems very likely that this new mode of eruption may bear on that problem, particularly in view of the identity of the magma which gave rise to both. The occurrence of other dikes south of Sierraville and 50 miles to the southeast in the Carson Range shows that the phenomenon was not local. The author intends to explore more fully the origin of the andesite mudflows and the bearing on that problem of the process herein described.

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MIDDLE DEVONIAN BONE BEDS OF OHIO

BY JOHN W. WELLS

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ABSTRACT

The Middle Devonian limestones of central Ohio consist of two formations, the Columbus (late Ulsterian) and the Delaware (early Erian). Within these are at least four thin bone beds: the First, 10 feet below the top of the Columbus in Franklin and southern Delaware counties, the Second, at the contact of the Columbus and the Delaware from Franklin county north to Lake Erie, the Third, 26 to 30 feet above the base of the Delaware in Franklin and Delaware counties, and the Fourth, 2 feet above the Third at Delaware. The Rocky Branch bone bed occurs in southeastern Indiana at the approximate horizon of the Second. These beds vary considerably in development, being absent at some localities and a foot or slightly thicker at others. They consist of clastic accumulations of crinoidal debris, innumerable scales, plates, teeth, and bones of fishes, conodonts, ostracods, and Foraminifera, relatively few macrofossils, mixed with rounded sand grains and a small amount of clay-size constituents, more or less thoroughly cemented by calcite. Another bone bed, the East Liberty, occurs between the Columbus formation and the Upper Devonian Ohio shale in the Bellefontaine Devonian outlier in Logan County, Ohio. It is mostly sand grains cemented by dolomite, with some fish material and a few phosphatic nodules, and is considered younger than the bone beds of central Ohio—perhaps of Olentangy age. The Kiddville layer in the lower part of the Boyle limestone of eastern Kentucky is similar to the East Liberty bone bed lithologically and faunally and probably represents approximately the same horizon.

All these bone beds occur on the flanks of the Cincinnati arch, and none is now known in equivalent formations away from this structure. Most of the fish material is believed to have come from the fresh-water environments of the middle Paleozoic lowland area of Cincinnatia and is found not only concentrated in the bone beds but also thinly diffused throughout the enclosing limestones. These bone beds do not represent catastrophic annihilation of indigenous marine fish communities but are rather concentrates accumulated during diastems resulting from the fluctuations with respect to wave base of the very shallow sea bordering Cincinnatia. In places they represent lag concentrates, in others rapid subaqueous accumulations of coarser material transported from areas of lag concentrates with bypassing of finer particles, and in still others aeolian deposits derived from subaerial exposures of lag concentrates.

INTRODUCTION

> "There have been elaborate treatises written on those ornate flooring-tiles of the classical and middle ages. . . . But did any of them ever tell a story half so instructive or so strange as that told by the incalculably more ancient . . . tiles of the Paleozoic. . . .?"
>
> —Hugh Miller: *Rambles of a geologist.*

Several years ago the writer began a study of the microscopic fish remains of the well-known bone bed at the top of the Middle Devonian Columbus formation in central Ohio. An exceedingly interesting fauna rich in new genera and species was found, and from this paleontologic study arose the paleoecological problem of the environments of the fishes. Closely related is the problem in sedimentation involved in determining the mode or modes of origin and accumulation of the bone-bed materials. Previously proffered explanations of the origin of the bone beds have interpreted them either erroneously or incompletely. In the present paper an attempt is made to explain more adequately the origin of these bone beds, not with the thought of definitely settling the problem, for certain aspects have not been investigated, but more with the hope of provoking further study. Bone beds are not uncommon, but they have been relatively neglected.

In later papers the writer and Dr. Grace Anne Stewart intend to describe the fish remains, conodonts, ostracods, Foraminifera, and sponge spicules, which are here referred to only incidentally.

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MIDDLE DEVONIAN LIMESTONES OF CENTRAL OHIO AND THEIR BONE BEDS

GENERAL STATEMENT

The Middle Devonian limestones of central Ohio consist of two formations—a lower, the Columbus formation of late Ulsterian age, in which at least three members can be differentiated, and an upper, the Delaware formation of early Erian age, which is not yet satisfactorily subdivided.[1] The stratigraphic relations of these units in the southern part of their outcrop are shown in Figure 1.

Within these formations at least four bone beds are known in central Ohio, while a fifth is known in the Bellefontaine Devonian outlier in Logan County, west-central Ohio. They are here identified as the First, Second, Third, and Fourth bone beds, according to their stratigraphic order from oldest to youngest, the lower two occurring in the upper part of the Columbus formation, and the upper two in the upper part of the Delaware formation. The bone bed in the Bellefontaine outlier occurs between the Columbus formation and the Ohio shale and is termed the East Liberty bone bed.

The bone beds are thin, more or less local zones of varying concentrations of pelopsammic material, much of it organic. Most of the organic constituents consist of very small, generally worn scales, spines, teeth, armor plates, shagreen denticles, and bits of bone of agnathid (heterostracan and osteostracan), arthrodiran, ptyctodontid, acanthodian, selachian, and crossopterygian fishes (Pl. 1, Fig. 1). Less common constituents are conodonts, arenaceous Foraminifera, ostracods, scolecodonts, sponge spicules, and lycopod spore exines. Some of the fossil remains are exquisitely preserved. Locally there are "crinoidal sands" composed of large numbers of pelmatozoan ossicles. All these constituents, except a few larger fish fragments and pelmatozoan remains, are microscopic—that is, less than 5 millimeters in diameter. Fewer in numbers are macroscopic fossils—corals (*Hadrophyllum d'orbignyi*), bryozoans, brachiopods, gastropods, and pelecypods. The whole forms a thanatocoenotic assemblage of unusual interest both faunistically and stratigraphically and can be compared with such deposits as the Conodont limestone (uppermost Erian) in western New York, the Ludlow bone bed (Downtonian) in England, the bone beds at the base of the Rhaetian in Gloucestershire and Württemburg, the upper Upper Silurian bone beds on the island of Oesel, and others.

Southward from Columbus, the Columbus and Delaware formations are largely concealed, then entirely absent, so that the overlying Olentangy shale directly overlies the Upper Silurian. North of Columbus these formations crop out more or less continuously as far as Kelleys Island in Lake Erie (Fig. 2), and the Second bone bed, at the top of the Columbus, can be traced definitely from Columbus to Dela-

[1] Stauffer (1909, p. 29–38) recognized 13 zones within these formations—from A through H in the Columbus, and I through M in the Delaware. Those of the Columbus can usually be discriminated in Franklin and Delaware counties, but those of the Delaware can rarely be recognized, with the exception of L—the *Hadrophyllum* zone, a bone bed.

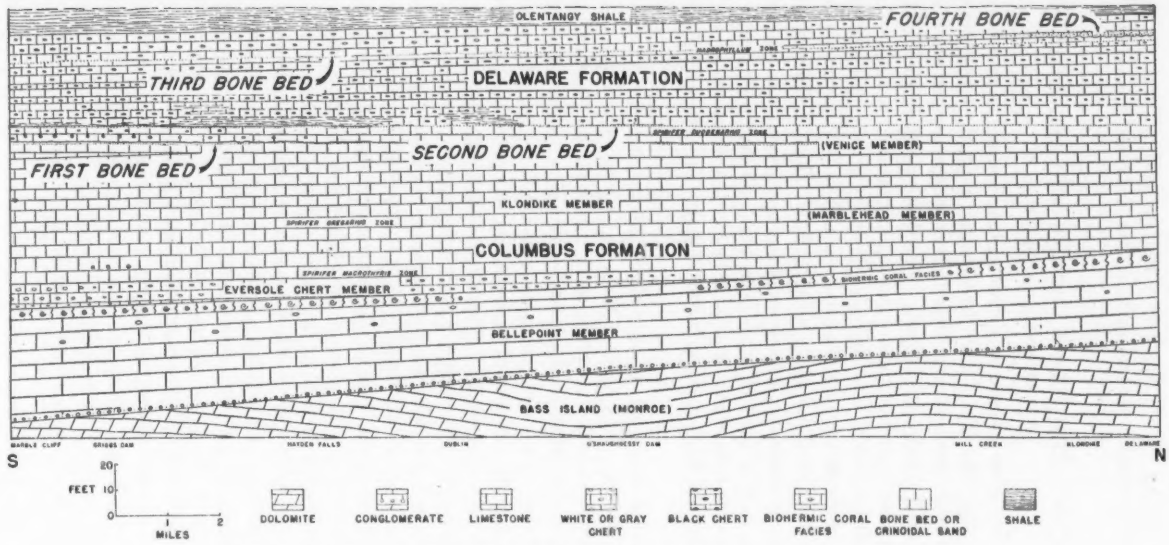


FIGURE 1. *Generalized meridional section in Franklin and Delaware counties, central Ohio*

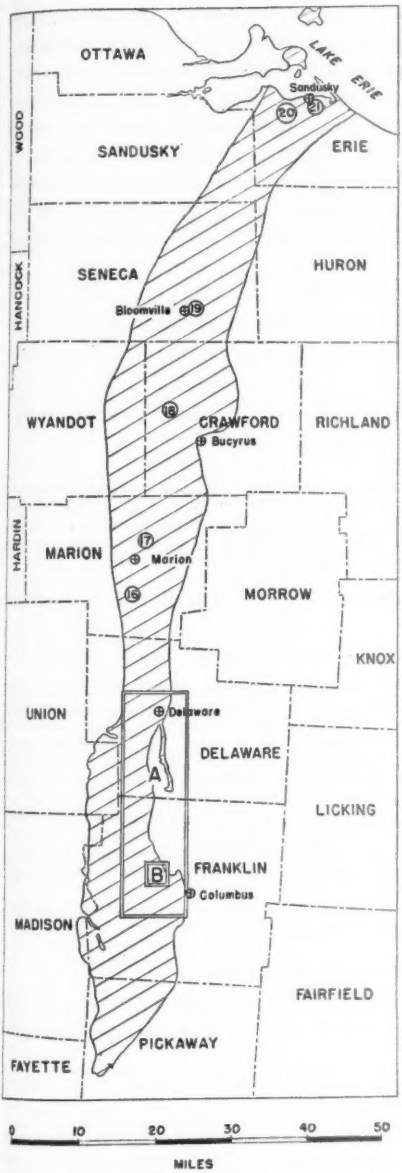


FIGURE 2. *Outcrop of Middle Devonian limestone formations in central Ohio*

(Numbers indicate bone bed localities; A and B are areas shown on larger scale maps, Figures 3 and 4).

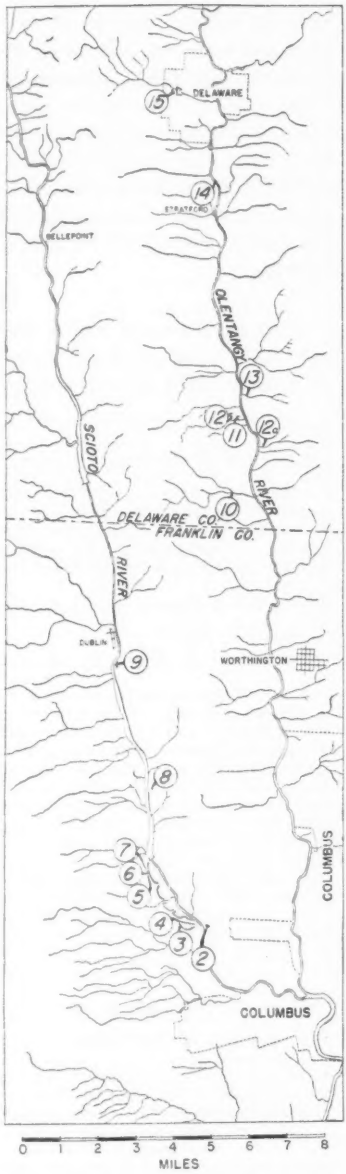


FIGURE 3. *Bone bed localities in Franklin and Delaware counties*

ware (22 miles) and probably to Marion (45 miles). North of Marion, a weakly developed bone bed, presumably the same one, has been traced as far as Marblehead Peninsula (120 miles). The other bone beds—the First, Third, and Fourth—have been found only in Franklin and Delaware counties. Their principal outcrops are shown in Figure 3. Similar bone beds are known from stratigraphical equivalents in east and south-central Kentucky and southeastern Indiana, but none is known in Middle Devonian limestone formations farther east[2] in the Appalachian geosynclinal area or north in Michigan, Ontario, and New York. The significance of this distribution around the borders of the Cincinnati arch (Fig. 7) will be developed later on.

SECOND BONE BED

The bone bed at the top[3] of the Columbus formation in central Ohio was the first described[4]; it was referred to by Edward Orton in his report on the geology of Franklin County (1878, p. 610, 628) as

". . . one of the most remarkable layers, indeed, in the entire series of American Paleozoic deposits."

He referred to its origin in these words (p. 628);

"There came a time in the history of the Corniferous sea when fishes of this genus [*Onychodus*] constituted its most conspicuous and abundant inhabitants. There was scarcely a square foot of the sea-floor for hundreds of square miles that did not contain a tooth or plate of the jaw of some fish that had met its fate in the waters above. There were considerable areas that seem to have been the gathering grounds, perhaps the breeding stations, of these tribes of the sea."

He further compared it with the modern deep-sea deposits in which sharks' teeth are occasionally found.

In 1889, J. S. Newberry described the accumulation of this bed as follows:

"Most of the fragments are worn and rounded, and have evidently been subjected to some sort of triturating agency. They have the aspect of having been beach-worn, but the mass is almost entirely organic, and it is difficult to understand how it could have accumulated along a shore line without some intermingling of sand or pebbles. It forms a thin layer in a thick sheet of organic sediments, which must have been deposited in comparatively deep water, for no land wash of any kind is associated with it. It has seemed to me that this fish bed was made up of excrementitious matter, and that it represents the hard and indigestible parts of fishes which have served as food for other and larger kinds. On this supposition the fragmentary and worn appearance of the bones would be attributable to the crushing, maceration, and partial digestion which they have suffered. If this is the true history of the deposit, it accumulated in some nook or bay, perhaps bordering a coral reef, where large and small fishes congregated age after age until their "kjokkenmöddings" formed a sheet some inches in thickness all over the sea bottom. [p. 30]

". . . the limestone in which they lie was deposited in comparatively deep and still water, and they could only have been broken and worn by violence or the digestive energy of the fishes which swallowed them. [p. 24]"

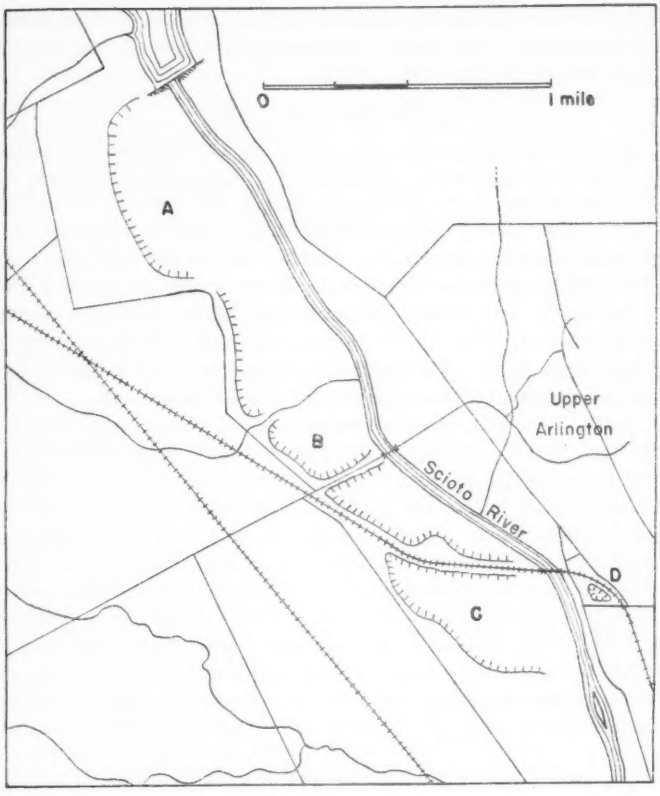
FIRST, THIRD, AND FOURTH BONE BEDS

Until 1933, the Second bone bed (uppermost Columbus) and the Third bone bed near the top of the Delaware formation, which was first described by Stauffer in

[2] Through the kindness of Messrs. Wilber Stout and R. S. Clark the writer is informed that no bone beds appear in the complete sections of the Devonian limestones exposed in the deep shafts recently put down at Barberton, Summit County, Ohio, about 60 miles east of the central Ohio outcrops.

[3] This layer forms the uppermost part of the top stratum of the Columbus formation and is composed largely of material derived from the Columbus. It resulted from events belonging to the closing phase of Columbus time and accordingly is not part of the Delaware formation, as supposed by Westgate and Fischer (1933, p. 1168–1169), but belongs with the Columbus. (*See* Twenhofel, 1936, p. 684.)

[4] The first mention of this bed seems to have been made by Newberry in 1873 (1873d, p. 301; 1873b, p. 143) when he referred briefly to "fish-beds" in the limestones at Sandusky and Delaware.



A- Scioto Quarry
B- Williams Quarry
C- Hobo Quarry
D- Marble Cliff Station Quarry

FIGURE 4. *Marble Cliff quarries group*
West of Columbus, Ohio

A—Scioto Quarry, B—Williams Quarry, C—Hobo Quarry, D—Marble Cliff Station Quarry

1909 (p. 29) as the *Hadrophyllum* zone, received no further special attention. Then Westgate and Fischer (1933) published a short but significant paper describing them in considerable detail and adding the account of another bone bed—the Fourth—which is just above the Third in the Delaware quarries. Still another bone bed can be distinguished in the Columbus area. This has been discovered recently in the quarries along the west side of the Scioto River opposite Columbus (Fig. 4) about 9½ feet below the top of the Columbus formation (Localities 3, 5, Fig. 3) and in the Miami Stone Company quarry on the west side of the Olentangy River valley in southern Delaware County (Locality 11, Fig. 3). It is diffuse and less concentrated

than the higher ones and occurs sporadically in the upper 2 or 3 inches of the heavy crinoidal stratum that lies between the two "smooth layers", both of which are strongly wave-rippled in places.[5]

EAST LIBERTY BONE BED

In west-central Ohio about 45 miles west of the central Ohio Middle Devonian outcrops a bone bed of Devonian age is found that is entirely unlike those of central Ohio. This bed is seen at the top of an exposure of the Columbus formation in the quarry of the East Liberty Stone Company a mile west of East Liberty, Logan County, and at other outcrops near by, notably in the floor of the abandoned quarry in the Ohio shale several miles farther west. This is in the area known as the Bellefontaine outlier, the only mass of Devonian rocks known in Ohio west of the outcrops on the east flank of the Cincinnati arch, excepting those in the extreme northwestern part of the State. The stratigraphic relations of the Devonian limestones in this outlier to those exposed in the sections to the east are uncertain (Stauffer, 1909, p. 108–109), but the Delaware formation and the Olentangy shale are absent, the Ohio shale resting unconformably upon dolomitic limestone thought to be equivalent to the lower part of the Columbus formation. The lower, thicker strata of this Columbus equivalent are nearly pure dolomite; the upper, thinner beds, which vary considerably in total thickness in different parts of the outlier, are also dolomite, with considerable fossiliferous chert. Typical Columbus fossils occur throughout, except in the uppermost sandy bed or beds that constitute a sort of bone bed. That the whole Columbus formation, as known in the easterly sections, occurs here, is unlikely; the massive lower beds may represent the Bellepoint member (Fig. 1), and the cherty upper beds the lower part of the Klondike member, whereas the uppermost arenaceous layers may be very much younger, perhaps of Olentangy age, and homotaxial with the Hillsboro sandstone of Highland County, south-central Ohio.

The bone bed is a dolomitic sandstone. (Pl. 1, fig. 3) containing abundant phosphatic nodules, many of which are internal molds of small mollusks and other fossils; there are lesser amounts of worn fish remains and conodonts, but virtually no other fossils. In places the sandstone is light drab and slightly ferruginous, whereas in others it is dark bluish-green gray and contains abundant pyrite. At many places the uppermost part is a discontinuous sheet of granular pyrite. The upper surface is rolling, the depressions being filled by black Ohio shale. The thickness of the top bed, the bone bed, is commonly less than a foot, but the arenaceous character extends downward for 10 feet or more, and the lower boundary of the bone bed is gradational, at least in places.[6] The sand grains are practically all colorless quartz, some of them rutilated, well rounded, and frosted, with a small admixture of clay-sized constituents.

Remains of 11 species of fish have been identified from this bed. Three of these

[5] In the now-abandoned and largely concealed Casparis quarry on the east side of the Scioto River the "smooth layers" are 9 feet 7 inches and 10 feet 6 inches, respectively, below the top of the Columbus.

[6] Hill, in his report on the geology of Logan County (1878, p. 485–486) refers to local deposits of fine sandstone in the upper layers of the "Corniferous" some 55 feet above the "Helderberg" limestones, in the vicinity of West Liberty. These seemingly represent this same phase.

do not occur in any of the four bone beds previously described or in the Rocky Branch bone bed in Indiana to be described, but they are found in the Kiddville bone bed of Kentucky, also to be described. The last-mentioned deposit has nearly the same lithological character as the East Liberty bone bed except that in the Kiddville angular quartz grains are more abundant than rounded, frosted ones. Faunally, the East Liberty and Kiddville beds are alike, but the former contains none of the curiously uncrushed spore exines that are abundant in the latter.

PHYSICAL CHARACTERS OF BONE BEDS

The physical features of the four[7] central Ohio bone beds and the East Liberty bone bed (Pl. 1, figs. 1, 3) are summarized on the bases of personal observation and the published descriptions of Westgate and Fischer (1933):

1. First bone bed.

(a) *Lithology.*—Thick, fine-grained, gray to pale yellow-brown crinoidal limestone, with fish fragments concentrated in upper 2 or 3 inches. Little chert in residue. Some angular quartz grains and a few larger (0.3 mm.) rounded, frosted ones, especially at Locality 11.

(b) *Relations.*—Conformable, lying within a single thick stratum which is bounded above and below by a "smooth layer".

(c) *Occurrence.*—Columbus formation, 9½ feet below top, in Franklin and southern Delaware counties.

2. Second bone bed.

(a) *Lithology.*—Crinoidal limestone, with fish fragments scattered in varying concentrations, locally absent, attaining a maximum thickness of 16 inches, commonly in two layers, with some limestone pebbles. Bone material may be excessively abundant in top 2 inches with much less pelmatozoan material. Residue of some chert, quartz in angular or large (0.8 mm.) rounded, frosted grains, zircon, tourmaline, garnet, and hornblende.

(b) *Relations.*—Diastematic generally in southern part of out-crop area, conformable in northern part. Where diastematic, it rests on rolling uneven surface of top bed of Columbus formation, of which it is a part. Where apparent conformity exists, the transition from the Columbus to the Delaware is marked by a faunal change noted in the weakly defined bone bed.

(c) *Occurrence.*—Columbus formation, at very top, from Columbus northward to Sandusky, Ohio.

3. Third bone bed.

(a) *Lithology.*—Coarse crinoidal limestone, gray where unweathered, locally absent, attaining a maximum thickness of 15 inches, with abundant *Hadrophyllum d'orbignyi* and fish remains. Some limestone pebbles. Residue of well-rounded and frosted quartz grains up to 0.5 mm., some heavy minerals; rare replacements of fish bits by precious opal; pyrite common in places, giving the bed a rusty appearance when weathered.

(b) *Relations.*—Diastematic, mostly sharply differentiated from underlying limestones; may occur as filling of shallow depressions or well-defined mud cracks.

(c) *Occurrence.*—Delaware formation, 26 to 30 feet above the base, in Franklin and Delaware counties.

4. Fourth bone bed.

(a) *Lithology.*—Thin-bedded brown crinoidal limestone with a total thickness of about 4 feet. Fish fragments most abundant in basal few inches. Residue of chert, well-rounded and frosted quartz and chert grains up to 1 mm., zircon, rutile, tourmaline, and garnet.

[7] A fifth bone bed may be present here and there at the top of the Delaware formation at its contact with the overlying Olentangy formation. This contact can be found only very rarely, and at the only locality known in recent years, on Bartholomew run, a tributary to the Olentangy River (Fig. 3), it is concealed. Its relations are very like those of the bone bed described by Udden (1899, p. 71, 72) from the base of the Upper Devonian Sweetland Creek formation in Muscatine County, Iowa. This bed overlies the Cedar Valley limestone, on the unevenly eroded surface of which it rests. It was interpreted erroneously by MacFarlane (1923, p. 297) as a volcanic dust deposit.

(b) *Relations.*—Slight nonconformity with underlying beds.

(c) *Occurrence.*—Delaware formation, 2 feet above Third bone bed in old quarries at Delaware, Ohio.

5. East Liberty bone bed.

(a) *Lithology.*—Drab to bluish-green gray dolomitic sandstone up to 1 foot in thickness, containing many phosphatic nodules and much pyrite. Quartz grains colorless, rounded and frosted, many rutilated.

(b) *Relations.*—Diastematic, at top of sandy beds forming the upper strata of the Columbus formation, disconformably overlain by the Ohio black shale.

(c) *Occurrence.*—Between the Columbus formation and the Ohio shale in the Bellefontaine Devonian outlier, Logan County, Ohio.

Among the inorganic constituents, the lack of grains of glauconitic minerals and phosphatic nodules (except for the latter in the East Liberty bone bed) is notable, since they are commonly found in deposits similarly associated with diastems. More details of the character of the bone beds at different localities are included in the discussion of their origin.

MIDDLE DEVONIAN BONE BEDS OF INDIANA AND KENTUCKY

ROCKY BRANCH BONE BED, SOUTHEASTERN INDIANA

This name is applied here to the bone bed near the top of the Jeffersonville limestone at an outcrop on Rocky Branch, northwestern Jennings County, Indiana. Newberry (1873b, p. 265) once mentioned a bone bed about 2 inches thick in the "Corniferous" limestone at North Vernon, Jennings County, Indiana, but he gave no description of it. The writer has been unable to find any other mention of this layer in subsequent discussions of Indiana Devonian stratigraphy. The latest paper on the subject, by Campbell (1942), which contains a number of detailed sections of the Devonian limestones on this area, makes no mention of such a bed. A bone bed does exist in this region, however, at or near the top of the Jeffersonville (= Columbus) formation, concerning which some information has been provided by Dr. C. A. Malott, of Indiana University, who says (personal correspondence):

> "Usually the fish remains are concentrated in thin bands rarely more than two inches thick. The specimens came from along State Highway 7, from the bed of Rocky Branch, in northwestern Jennings county, about 3 miles northwest of Scipio. The horizon of their occurrence is about 4 feet below the top of the [Jeffersonville] limestone and at a place where the Beechwood is missing. I have seen the same bone bed in the same highway where it crosses Six Mile creek, near the village of Queensville, Jennings county. In the quarries at North Vernon, the fish remains are much scattered through some 10 feet of the formation below the thin Beechwood limestone there. Some 20 years ago I visited the Newberry locality east of North Vernon, but the quarry had so grown up that little rock was visible."

The specimens referred to are nearly identical in lithologic character and micropaleontology with typical pieces of the Second bone bed of central Ohio (Pl. 1, figs. 1, 2). The only differences are the presence in the Rocky Branch bed of numerous small rounded phosphatic nodules having the form of internal molds, replacements, or encasements of small gastropods, pteropods, pelmatozoan ossicles, and bone fragments, and the more worn condition of the bone material, associated with considerable rolled frosted quartz and little or no angular quartz. That this bone bed and the First and Second bone beds of central Ohio represent very nearly the same conditions of origin during the same period of time is evident, but they were

more prolonged in the case of the Rocky Branch bone bed, at least at the locality whence the present specimens came. This bone bed and the lower two of the four central Ohio bone beds occur at practically the same stratigraphic horizon and were the results of simultaneous shifts of the same land mass.

KIDDVILLE BONE BED, EAST-CENTRAL KENTUCKY

In 1906 Foerste (p. 16, 93–97) described a layer in the Boyle limestone of east-central Kentucky that contains abundant fish remains. This he termed the Kiddville bed or layer (1906, p. 16). It occurs at the base of the Middle Devonian limestones developed east and south of the Cincinnati arch.

> "It usually is strongly argillaceous, and frequently contains coarse sandy particles, some of which are black and nodular in character. This layer is often less than four inches in thickness, but frequently contains fish remains, including teeth and plates. . . . It is well exposed along the railroad west of Preston, in Bath county; north of Berea, along the railroad, in Madison county; and at various localities near Indian Fields, in Clark county." (p. 16.)

The bed is not always at the very base of the Boyle limestone, however:

> "A mile and a half east of Moberly [Madison county], on the western side of Muddy creek, the thickness of the Devonian limestone appears to be fifteen feet eight inches. The lowest layer consists of gray, well-bedded, sandy limestone, two feet thick, overlaid by an equal thickness of similar rock; between these layers of limestone there is a thin film of rock containing fish teeth and small black nodular particles. Wherever these nodules occur, careful search will usually result in the discovery of fish remains, and in this connection, therefore it is of interest to note that in the area between Whites and the localities three miles east of Bobtown, where the thickness of the Devonian limestone is so much reduced, the black nodular particles are rather common, and the rock is decidedly sandy." (p. 94.)

Foerste (p. 96–97) notes that Linney, in his report on the geology of Bath County, states that the layer containing fish remains is present in Marion, Boyle, Lincoln, Garrard, Madison, Clark, Montgomery, and Bath counties. Savage (1930, p. 58, 61) reports it also in Casey County astride the southern flank of the arch and indicates that generally it persists as a basal limestone or in many places the only limestone unit present.

Specimens of this layer from a locality near Hargett, Estill County, Kentucky, collected by Dr. C. C. Branson, consist of a crumbly, very ferruginous sandstone with a weak calcareous cement, containing relatively few fossils. Many of the sand grains are rounded and frosted or polished, some of them retulated; many grains are angular, commonly tiny, more or less perfect, quartz crystals that do not seem to be secondarily enlarged (Pl. 1, fig. 4). Little or no phosphatic material was found in this particular material. The fossils consist of macerated inarticulate brachiopods, fragmentary conodonts, fragments of fish teeth, and micropiscine scales and teeth. Remarkable are the many unflattened spore exines (*Sporangites?*), some intact, others with the usual tears or cracks. Nearly all the acanthodian scales are very worn, whereas the selachian teeth and shagreen denticles are relatively fresh. This suggests a commingling of fossils of different ages. The Kiddville layer is a weakly developed bone bed entirely different from all the bone beds previously mentioned except the East Liberty. Its origin and relationships present an interesting problem that is beyond the scope of the present paper.

Stratigraphically the Kiddville bone bed seems to be considerably younger than

the central Ohio bone beds. In the Devonian terrain of south and east-central Kentucky no equivalent of the Columbus formation in Ohio and of the Jeffersonville in northwestern Kentucky and southeastern Indiana was deposited; and the Boyle strata of eastern and southern Kentucky are probably even younger than the Delaware and Sellersburg formations. The micropiscine fauna of the Kiddville bed not only has some species (reworked specimens) common to the central Ohio bone beds but also several selachian species (unworn specimens) found in the East Liberty bone bed that are suggestive of the uppermost Middle Devonian Geneseo shale and Conodont bed of western New York. Cooper and Warthin (1942, p. 883) have recently suggested that at least part of the Boyle strata represents the later Erian Beechwood of Indiana, which they consider equivalent to the Centerfield horizon of New York.

FAUNAS OF THE BONE BEDS

GENERAL STATEMENT

The pelopsammic biotope which existed during the times of bone bed accumulation was certainly a favorable one[8] for a certain type of benthonic community probably consisting almost exclusively of animals, associated with few or no algae. Whatever the nature of these biocoenoses, they are now represented only by thanatocoenotic fossil assemblages that are only minuscule parts of once teeming communities. Detritivores and scavengers must have been active, and few remains, especially the carcasses of fishes, wherever they may have come from, escaped the trituating and solvent effects of rugged masticatory and digestive processes, as envisaged by Newberry. The fossils, with few exceptions fragmentary and broken, give only a badly smudged sketch of the real picture of things then—lithotopes[9] and thanatocoenoses can rarely clearly reveal the biotopes and biocoenoses of the past.

Few, if any, of the fossils of the bone beds are found only in the bone beds, except the apparently exclusive species *Hadrophyllum d'orbignyi*, and those that do occur in them, with the exception of most of the fish remains, probably represent eurytropic forms of the shallow limestone seas. *H. d'orbignyi*, a button-shaped rugose coral, appears to have flourished on pelopsammic bottoms but not on soft pelitic ones. This is true of many modern scleractinian corals having the same growth form, such as *Fungia* and *Micrabacia*. Some paleocyclids, however, preferred soft bottoms, such as *Hadrophyllum aplatum*, so abundant in parts of the olive-gray phase of the Bendian Smithwick shales of central Texas. (*See* Plummer and Moore, 1921, Pl. 7, fig. 3.)

FISH "FAUNA" OF THE BONE BEDS

A detailed analysis of the distribution of fish remains in the bone beds is unnecessary here. Fossils representing the following groups of fishes have been identified

[8] In modern shallow seas such biotopes may support a prolific fauna, as suggested by the following quotation by Kindle (1919, p. 363) from Peterson:

> The *Modiola* epifauna occurs [in Skagerrak and Kattegat] especially where there is a strong current close to the bottom, clearing away the finer particles [*i.e.*, the bottom is above wave base] so that stones and shells lie exposed, affording sites for attachment for the *Modiola*, which here occurs in such numbers as entirely to cover the bottom for great tracts in the current channels.

[9] *Lithotope*,—a paleoecological term proposed here for the sedimentary rock record of a biotope. Thus, a *biotope* with its special life community or *biocoenosis*, is preserved as a *lithotope*, with its fossil community or *thanatocoenosis*, with the reservation that the parallel cannot be complete in most instances because thanatocoenoses rarely represent a biological balance and usually contain some forms not living in the original life community of the recording biotope.

from the bone beds. Most are microscopic but often complete parts of the exoskeleton (Fig. 5):

Subclass Ostracodermi
  Order Heterostraci
    Family Drepanaspidae (indetermine plates)
  Order Osteostraci
    Family Cephalaspidae (1 new genus with 3 new species) (Fig. 5, a-b)
Subclass Placodermi
  Order Acanthodii (*Machaeracanthus major, Gyracanthus?* n.sp., *Acanthoides dublinensis* and 2 new species, *Plectrodus*, 3 new species, 2 new genera with 6 new species) (Fig. 5, c-e)
  Order Arthrodira
    Family Coccosteidae (*Coccosteus spatulatus*)
  Suborder Ptyctodontida (Ptyctodus sp., Rhynchodus sp., Palaeomylus sp.)
Subclass Chondrichthyes
  Order Selachii
    Suborder Pleuropterygii
      Family Cladoselachidae (3 new genera with 4 new species) (Fig. 5, f, h, i)
    Suborder Pleuracanthodii (*Phoebodus* with 2 new species) (Fig. 5, 8)
Subclass Osteichthyes
  Division Crossopterygii
    Order Rhipidistia
      Family Onychodontidae (*Onychodus sigmoides*) (Fig. 5, j, k)

The distribution of these forms in the bone beds falls into two groups: (1) the four central Ohio bone beds and the Rocky Branch bone bed of Indiana, in each of which are more or less uniformly found 26 of the 29 types listed; (2) the Kiddville and East Liberty bone beds, in each of which are found 3 forms (selachians) not found in the other bone beds, plus 10 that are. This second group, as has been suggested, is probably considerably younger than the first. Nearly all except the 3 species restricted to the Kiddville-East Liberty bone bed group are also found thinly diffused throughout the upper part of the Columbus (Klondike member) and throughout the Delaware.

ENVIRONMENT OF THE FISHES

In previous discussions of the Ohio bone beds it has been tacitly assumed that the included fish remains are of fishes that dwelt in marine environments. But did these all live in the marine biotopes in whose lithotopes their scant remains are now found, or did they inhabit the fluviatile, lacustrine, or estuarine environments of some near-by lowland?

Some uncertainty still exists concerning the environments of the early vertebrates, but, on the basis of the available evidence from North American occurrences of earlier Paleozoic fishes, Romer and Grove (1935, p. 851) conclude that the earliest forms were all dwellers in fresh waters. They suggest that in the Devonian:

(a) The ostracoderms were essentially fresh-water with some tendency in the heterostracans towards a marine life.

(b) Some of the arthrodires migrated in Lower Devonian time into the seas.

(c) The antiarchs remained almost wholly in fresh water.

(d) The acanthodians remained exclusively in fresh water.

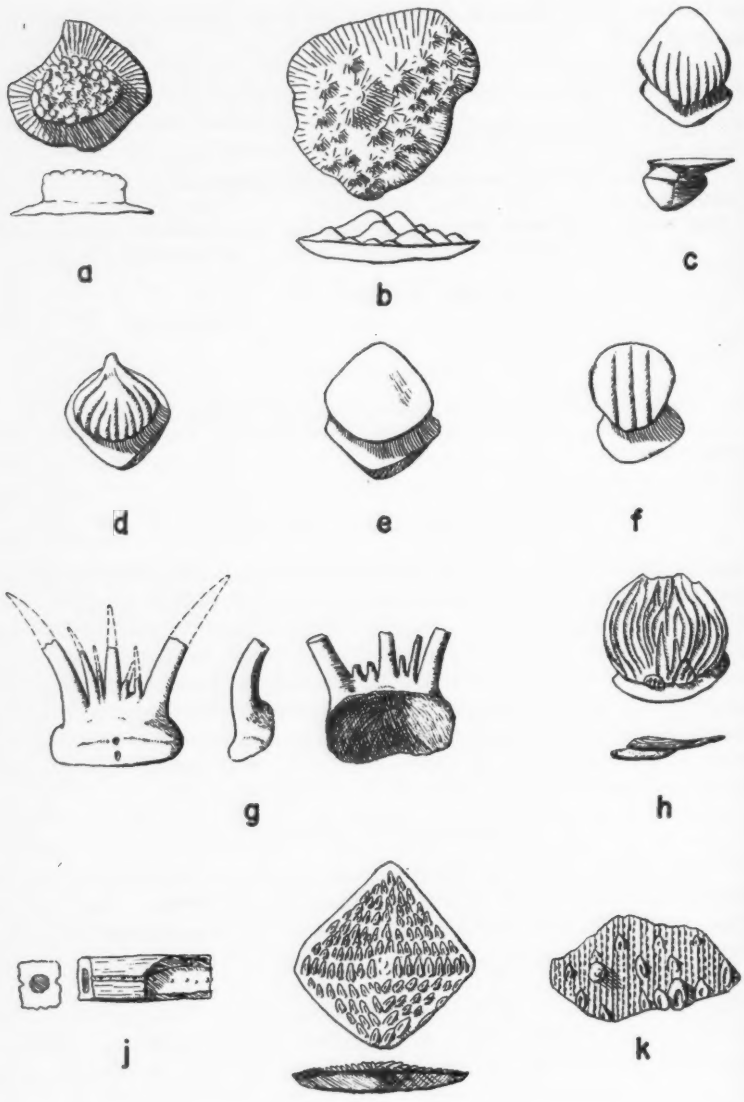


FIGURE 5. *Bone bed fish remains*

a, b,—cephalaspid tesserae; c, d, e,—acanthodian scales; f, h, i,—cladoselachid dermal denticles; g,—pleuracanthid tooth; j, k,—crossopterygian fin ray and scale fragments. (a, g, h, i, j,—×10; b, c, d, f, k,—×15; e,—×20) (a, b, c,—Third Ohio bone bed; d, e, f, j, k,—Second Ohio bone bed; i,—First Ohio bone bed; g, h,—Kiddville bone bed).

(e) The "sharks" developed a strong trend toward the sea at the beginning of the Devonian.

(f) The higher fishes remained mostly in the fresh waters.

(g) The dipnoans developed a short-lived marine branch in the Devonian.

Romer and Grove's data support these conclusions if it be accepted that the presence of fossil fish remains in marine strata indicates a marine environment for those fishes. Their data will not be reviewed here except to remark that the evidence for the existence of any truly marine fishes, including even selachians, during the early Paleozoic is not particularly strong. But if we accept their conclusions as a working basis the inference is that the marine environments of the Ohio Middle Devonian had practically no endemic fish fauna with the possible exception of rare dipnoans—so rare that the single known specimen[10] might rather be taken to indicate a normally nonmarine habitat—, sharks—some equally rare (*Psammodus*?[11] and *Cladodus*[11])—, and perhaps a few arthrodires (*Coccosteus*,[12] *Dinichthys*,[11] *Rhynchodus*, *Palaeomylus*, and *Macropetalichthys*[13]). The other fish groups (drepanaspids, cephalaspids, acanthodians, some "sharks", and crossopterygians), whose remains are by far more numerous, both numerically and specifically, in the bone beds and other strata, must have lived elsewhere in the fresh or brackish waters of a land area. More or less continuously during Columbus and Delaware time some floating carcasses of these fishes escaped the limnotic scavengers and drifted down to the sea where they settled to the bottom and soon only their hard parts remained, scattered thinly in the limy muds. Some may have been katadromous, moribund after spawning. When shifts of the strand occurred these remnants were concentrated in bone beds.

The existence of a lowland area is indicated not only by the presence of remains of fresh-water groups of fishes in the bone beds, but also by the distribution of the bone-bed-bearing Ulsterian and Erian formations in the present Cincinnati arch area and by the occasional discovery of traces of terrestrial vegetation (seed-ferns, lycopods, and sphenophyllids) in both the Columbus and Delaware formations (Newberry, 1889b, *int. al.*). An attempted visualization of the aspect of this lowland during Erian time is presented in Figure 6. The name Cincinnatia is here proposed for this recurrent insular or peninsular area that resulted either from the uplift of the Cincinnati arch or the effects of "differential lateral deposition" (Stout, 1942, p. 13), and which was a more or less constant feature of mid-Paleozoic geography. Newberry long ago recognized its existence and referred to it as the "Cincinnati island" (1873, p. 65, 68; 1889b, p. 52). Stauffer (1909, Pls. 14, 15) presented two paleogeographic maps of the region during Columbus and Delaware time, evidently modified from Schuchert's earlier maps (1903, Pls. 20, 21, with "Cincinnati Peninsula" during Columbus time, and "Cincinnati Island" during Hamilton time), in which it is represented as a peninsular area. Figure 7 is a new effort to represent

[10] *Dipterus eastmani* Stauffer (1909, p. 196, Pl. 17, figs. 14–17) from near the top of the Columbus formation at Whitehouse, Lucas County, northwestern Ohio.

[11] Known from unique specimens.

[12] Known from unique specimens of a gnathal element (*Liognathus spatulatus*), part of a cranial shield (*Protitanichthys fossatus*), and a median dorsal plate and supposed median ventral (*Coccosteus occidentalis*). Scattered fragments also occur in the bone beds. The habit of this fish was very doubtfully marine.

[13] Including *Acanthaspis armatus* (*Vide:* Gross, 1937, p. 57, and Heintz, 1937, pp. 12–14).

FIGURE 6. *Cincinnatia during the early Middle Devonian*

Near the stream are tall seed-ferns (*Eospermatopteris*?), with scrambling sphenophyllids and stiff lycopods. In the sluggish, muddy-bottomed river the great crossopterygian *Onychodus* surges after a small school of luckless acanthodians, while a cephalaspid scuttles for safety in the mud.

the paleogeography at the close of Columbus time while the Second bone bed was accumulating.

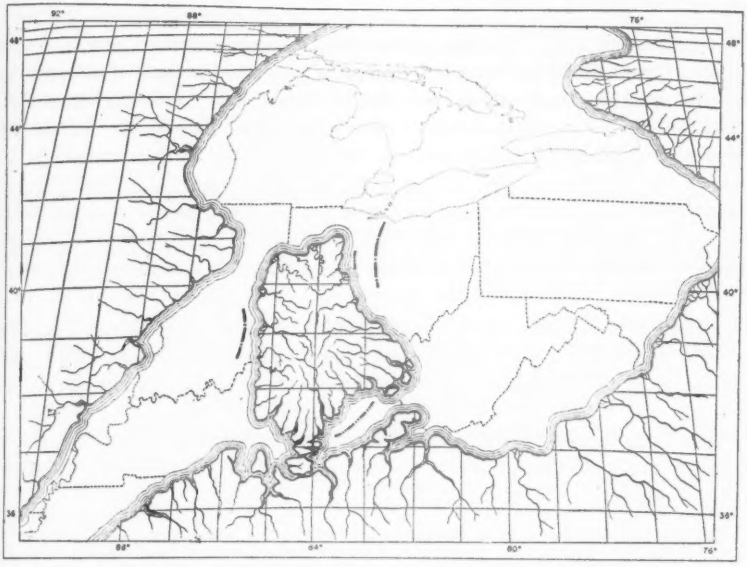


FIGURE 7. *Middle Devonian paleogeography of Cincinnatia and adjacent regions*

At close of Columbus time

ORIGIN OF THE BONE BEDS

PREVIOUS EXPLANATIONS

The ideas of Orton and Newberry on the origin of the Second bone bed of central Ohio have been quoted. Orton (1878, p. 628) suggested that at the time of accumulation of this bed fishes constituted the main faunal element of the local Devonian seaways, and therefore little but their remains piled up on the sea floor. Newberry (1889, p. 30) had much the same idea in comparing the bone-bed deposits with kjokkenmöddings, but he stressed a supposed rather deep-water origin of the bone bed which is not fully in harmony with his suggestion of the presence of coral reefs. Stauffer (1909) has described briefly the Second and Third bone beds but offered no comment on their origin or significance. In 1911 he (p. 21) re-offered, without critical comment, the old idea that the Columbus sea was a feeding ground for the fishes whose remains contributed to the accumulation of bone beds and further suggested the possibility of wholesale destruction of fish by some sudden change in the condition of the sea or by some agency of unknown cause, like those changes that have been noted in modern times in the shelf seas.

In 1919 Kindle, in a discussion of inequalities of sedimentation, mentions the Second bone bed of Ohio and inclines toward the view that

"Sudden phenomena of this kind [phenomenal increase in bulk of microscopic life in fresh and salt water sometimes resulting in pollution of the water and destruction of all life in it[14]] must cause the sudden deposition on the sea bottom of unusual and extraordinary quantities of the remains of pelagic life of various kinds. If great numbers of fishes or other vertebrate animals were affected a bone bed might result." (p. 358.)

Macfarlane (1923, p. 127), argued that the Delaware formation is a fresh-water deposit and that the Second bone bed represents a sudden downpour of volcanic dust. It is perhaps unnecessary to add here that there is no trace of volcanic material in any of the Ohio Devonian bone beds. On a later page of his work Macfarlane offers a variant version (1923, p. 267):

". . . we would consider that after the deposition of the marine Columbus limestone, some sudden volcanic activity took place, that caused elevation of the land, formation of an extensive lake, destruction of great shoals of freshwater fishes whose soft parts decayed, but whose teeth, spines, and plates formed much of the fish or bone bed of two to six inches in thickness. Thereafter continued deposition of freshwater limestone [Delaware formation] went on, that is largely unfossiliferous, but which encloses . . . no invertebrates."

Macfarlane evidently was not acquainted with Stauffer's description of the Middle Devonian limestones of Ohio, which shows that the Delaware limestone, while not so fossiliferous as the Columbus, nevertheless has a fairly sizeable Erian marine fossil fauna.

Westgate and Fischer (1933), in their study of the lithology and relations of the Second, Third, and Fourth bone beds, recognized their origin as shallow-water clastic accumulations:

"The bone beds and their associated crinoidal limestones at the base and near the top of the Delaware limestone are regarded as mechanical sediments forming a sort of basal conglomerate above two unconformities. . . . This implies that the Devonian sea at the beginning of Delaware time, and again towards the end of the period, was so shallow that rather coarse material was shifted over the bottom." (p. 1170–1171.)

They are more explicit regarding the Fourth bone bed near the top of the Delaware, in writing that this deposit signifies

". . . shallow-water conditions—probably with emergence, followed by renewed sedimentation when coarse mechanical deposits were swept in, in origin partly organic (fish and crinoidal material), partly inorganic (quartz and accompanying heavy minerals)." (p. 1163.)

They did not, however, analyze the ideas put forward by Orton, Newberry, Stauffer, and Macfarlane, nor did they pursue further the interesting and important questions of the source and mode of accumulation of the clastic material, organic or inorganic. Before taking up these considerations, however, it is desirable to consider briefly a few other bone beds and speculations concerning their origin.

OTHER BONE BEDS

Geologic literature contains many references to bone beds and some descriptions of them, but there are very few discussions of their modes of origin and significance. Bone beds are a minor feature of sedimentation, but among other minor and more trivial features of sediments discussed in Twenhofel's *Treatise on sedimentation* and

[14] ". . . widespread extermination of a sedentary population of invertebrates may be brought about . . . by the sudden appearance of vast multitudes of minute organisms like *Peridinia*." (Dall, 1909, p. 502.)

Principles of sedimentation, the only reference to bone beds turns out to mean beds of bone coal.

In Württemburg the uppermost Triassic (Rhaetic) is an unfossiliferous sandstone containing sporadic irregular lens-like or channel-like deposits in which quantities of bones, teeth, and scales of "ganoids" and dipnoans, and bones of turtles and phytosaurs are common. These deposits lie on the uppermost member of the Keuper, the Knollenmergel, and fill depressions in the Keuper. Fraas (Hennig, 1922, p. 148) explained these deposits as the result of catastrophic overwhelming by the rapidly advancing Rhaetic seas of the organisms living in the channels or depressions of the Keuper strata.[15] Hennig (1922, p. 148, 149) was neither impressed nor satisfied with this explanation for several reasons, among them the fact that the bone beds consist entirely of the heavier and harder, more compact bits of skeletal material —teeth, fin-spines, and scales—which indicates sorting, and the fact that complete skeletons are exceptionally rare. He regarded these bone beds as the residue of formerly much thicker deposits from which the finer and lighter constituents had been sifted, the once complete fossils having been worked up and mechanically triturated—in other words, a lag concentrate that involves stratigraphic condensation.[16]

An important discussion of bone beds and associated crinoidal sands is found is Hoppe's paper (1932, p. 60) on the coelolepids and acanthodians of the Upper Silurian bone beds of the island of Oesel in the Baltic. He postulates four possible modes of accumulation of these bone beds and associated clastic deposits—modes that are applicable to other bone beds as well:

(1) Catastrophic annihilation of a fauna.
(2) Enrichment of organic constituents by washing out of inorganic material.
(3) Secondary enrichment of organic constituents as a result of cessation of sedimentation.
(4) Washing together of scattered material by water movements.

The Oesel bone beds occur at three horizons in the Ohesaare zone (K_4) of the Upper Silurian. They are from 6 to 24 centimeters thick, separated by dark shales and crystalline or saccharoidal limestones containing fish remains and other fossils sparingly disposed throughout. The total thickness of the zone is 3.65 meters. The lower bone bed, 0.48 meter from the base, is sandy, consists of two beds, 9 and 6 cm. thick, and contains single fish scales and worn fragments of bony plates and fin spines. In the middle and upper bone beds, 1.91 and 2.81 meters above the base, the fragments are well sorted, remains larger than scale size being notably absent. This suggests a separation according to grain size by water movements either farther from the shore or at least weaker than those operative during the accumulation of the lower bone bed. Fish remains other than the small scales are absent from all the bone beds.

Hoppe rejects all but the last postulate as applying to the Oesel bone beds. He mentions the possibility of catastrophic annihilation of the faunas by great storms

[15] North (1930, p. 173) suggests a similar origin of the synchronous bone bed at the base of the Rhaetic in Gloucestershire—the sea returned rapidly to the area occupied by a Keuper lake

> . . . and animals thus brought into the stagnant waters of the . . . lake were to a large extent killed off, with the result that the lower part of the Rhaetic series is in many places characterized by a "bone bed" consisting largely of rolled fragments of the bones and teeth of reptiles and fishes.

[16] *See* Twenhofel (1936, p. 691, 700) for a concise discussion of Heim's idea of "Kondensation."

that stir up the bottom muds rich in H_2S, and notes that such storms have occurred in recent times in Walfisch Bay. He rejects this and similar catastrophic phenomena, however, as a factor in the origin of the Oesel bone beds, not only because of the lack of evidence of any considerable amount of H_2S in the Upper Silurian sea but also because of the presence of fish material in lesser amounts throughout the whole series of strata. The second and third postulates—enrichment by washing out of finer material (stratigraphic condensation) and enrichment by cessation of deposition—are rejected primarily on grounds of the lack of other fossils in the bone beds and difference between the constituents of the lower bone bed and the upper two, for sand, rolled material, and fish remains occur in the lower, whereas little except small fish scales is found in the upper two. The writer thinks that Hoppe has not sufficiently considered some of the probable circumstances of accumulation, that simple washing together of the materials by water movements such as currents made by wind, tides, or marine circulatory currents, and wave motion, is inadequate in the case of the Oesel bone beds, and that the evidence here points rather to condensation of thinly disseminated fish and crinoidal material in lag concentrates on a sea bottom above wave base. Likewise Westgate and Fischer's (1933) essentially similar explanation for the origin of the central Ohio bone beds is inadequate inasmuch as it does not account satisfactorily for the source of the materials in them and explains their accumulation only in some places.

Some bone beds admittedly have developed as the result of the washing together in places on the bottom of thinly scattered materials. Two examples are the famous Ludlow bone bed in the Downtonian of England and a previously undescribed bone bed in the continental Upper Devonian Oneonta formation of New York. In both the mode of origin seems clearly indicated. Published descriptions of the Ludlow bone bed by Stamp (1923, p. 370, 371, 387) and Elles and Slater (1906, p. 203) and study of specimens sent the writer by Drs. Stanley Smith and L. H. Straw support the interpretation that this deposit occurs as thin, lenticular patches in hollows in the underlying beds (*Chonetes* shales). The contact between the bone bed and the underlying shale is sharp. The bone bed (Pl. 1, fig. 5) is cross-bedded, varying from a conglomerate of sand, rolled phosphatic nodules, ferruginous concretions and scattered limestone fragments up to 8 inches across, to a well-graded sandy mixture of sand grains and worn *Thelodus* scales and other fish remains (*Onchus*, *Sclerodus*, *Plectrodus*, etc.). Fossil invertebrates characteristic of the underlying beds also occur in it. It is regarded by Stamp (1923) as a brackish-water deposit laid down in a shallow lake or arm of the sea established by positive earth movements at the close of the Silurian and during the earliest Devonian.[17]

The bone bed in the Oneonta formation[18] (Pl. 1, fig. 6) is very similar to the Ludlow bone bed, but marine fossils are absent. The sharp contacts, cross-bedding, almost complete lack of clay-size constituents, and patchy distribution all indicate

[17] Macfarlane (1923, p. 110) says categorically that this and other bone beds
"... can be exactly explained as sudden deposits of volcanic dust, that in a few hours or days, had entombed and preserved myriads of plant and animal remains."

[18] The locality, found in the summer of 1941 by Clyde T. Hardy and the writer, is near the highway bridge over Bowman creek, 2 miles south of Tyner, Chenango County, N. Y., about 20 feet above the stream. The bed consists mostly of mingled fragments of a new genus of antiarch and crossopterygian scales, with much well-rounded, frosted quartz.

local concentration of coarser materials in shallow depressions here and there in shallow water by waves, currents, and tidal movements.

Brotzen (1934, p. 58) raises the question of the origin of "so-richly speciated bone beds" in his paper on the paleontology of an erratic boulder of bone-bed material from the Lower Devonian of the Baltic region but merely points out that the coarse nature of the deposit indicates strong water movements and suggests the effect of both transgressing and regressing seas, or in some cases fluviatile action.

OHIO BONE BEDS

Hoppe's rejection of the postulate of catastrophe in the case of the Oesel bone beds because of the presence of fish material throughout the whole series of strata and the absence of evidence of any considerable amount of H_2S in the waters is also applicable to the central Ohio bone beds. Locally the Third bone bed may contain considerable pyrite as fillings of slender tubular cavities (worm burrows?), as disseminated granules, or as replacements of fossils, especially ostracods. In a few places shallow pools of foul water probably existed temporarily during the accumulation of this bone bed, but the fish remains had already reached essentially their present condition. This phase is well shown at the Deep Run locality (no. 12a) (Fig. 8). Besides Hoppe's reasons for rejecting catastrophe, mention may be made again of Hennig's point of the absence of any separate skeletal remains in natural articulation and the great scarcity of unworn plates and scales of larger than very small sizes in the Rhaetic bone beds—a point applicable to the Ohio bone beds. In deposits containing remains of organisms that quite certainly were overwhelmed by sudden disaster, the completeness of the carcasses is notable,[19] as in the numerous *Bothriolepis* skeletons on slabs of Upper Devonian arenaceous shales from Scaumenac Bay (Patten, 1912, p. 378, Fig. 257), in Hugh Miller's "platforms of death" in the Old Red Sandstone of Scotland,[20] and in the "*Aëtosaurus*-nests" in the Württemburg Triassic (Hennig, 1923, Pl. 9b). Catastrophe may not always be eliminated, however, for not all the criteria against it as outlined above, especially the worn condition of the remains, are necessarily reliable. If annihilation were by sudden slumping or influx of sediments, the carcasses might indeed be buried well below the reach of nekrophages; in the case of poisoning by H_2S liberated by storm disturbances of the bottom, the diatactic resettling of the sediments might be accompanied by rather complete burial. But if annihilation were by the pollution phenomena described by Kindle (1919) and Dall (1909), or by other toxic reactions, temperature change, epidemics, or submarine exudations, then the carcasses, on sinking to the bottom, might have been worked over by scavengers when the waters cleared. This would leave only triturated remains. The latter possibility may be ruled out in the case of the

[19] Anderson has well summarized the various offered postulates of catastrophic annihilation (1933, p. 689) and points out that normal death results in dispersal of individuals and skeletal parts, and that intact carcasses imply sudden, abnormal death (p. 687).

[20] "At this period of our history, some terrible catastrophe involved in sudden destruction the fish of an area at least a hundred miles from boundary to boundary, perhaps much more. The same platform in Orkney as at Cromarty is strewed thick with remains, which exhibit unequivocally the marks of violent death. The figures are contorted, contracted, curved; the spines stick out; the fins are spread to the full, as in fish that die in convulsions." (1860, pp. 221–222.)

See also a figure of a magnificent slab of *Holoptychius flemingi* from Dura Den in the British Museum, in an article by W. P. Pycraft in the *London Illustrated News* for May 29, 1937.

Ohio bone beds because the fish remains appear to have been derived from very different environments (fresh-water) from those indicated by the lithotopes (marine) in which they are now found.

In a few places the Columbus and Delaware bone beds probably have originated like the Ludlow and Oneonta bone beds—by sweeping together of coarser materials

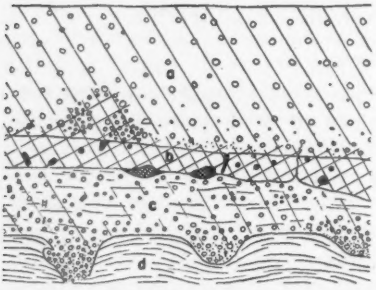


FIGURE 8. *Third bone bed at Deep Run, Delaware County (Locality 12a)*

a,—crinoidal limestone; b,—dark gray carbonaceous limestone with pyrite granules, nodules, and burrow fillings; c,—shaly crinoidal limestone with some bone material; d,—brown calcareous mud-cracked shale. ×1.

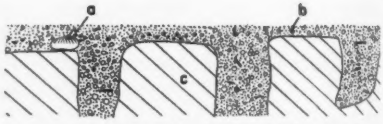


FIGURE 9. *Third bone bed at McCoy Road, Franklin County (Locality 8)*

a,—*Hadrophyllum orbignyi;* b,—bone bed resting on mud-cracked surface; c,—argillaceous mud-cracked limestone. ×1.

that lay scattered on the bottom, although, as pointed out by Westgate and Fischer, there is no evidence of cross-bedding as would be expected in such accumulations. Lenses and beds of crinoidal limestone occur locally in the Delaware formation in northern Ohio, and none of those seen by the writer shows cross-bedding. Cross-bedded crinoidal beds occur in other formations in Ohio, however, as in the Rogers Gap member at the top of the Cynthiana formation (lower Cincinnatian) at Covington, Kentucky (Foerste, 1895, p. 57–58). In the Delaware crinoidal beds the volume of finer constituents is appreciable, but in the Ordovician example it is very low. Lack of cross-bedding is not necessarily a criterion of condensation or lag concentrate, however, because original cross-bedding may be destroyed by the action of geophages and lithophages, as noted by Twenhofel (1935, p. 281).

The Third bone bed (*Hadrophyllum* zone) at the McCoy Road locality (no. 8) is a relatively coarse aggregate of fish remains, small angular quartz grains, larger well-rounded and frosted quartz grains, pelmatozoan ossicles, small, globular, or lentiform rugose corals, and a small amount of fine material. The nearly clear calcite cement gives a fossils-in-aspic appearance. The deposit lies on a strongly mud-cracked argillaceous limestone, filling 2-centimeter wide cracks in the limestone to a depth of several centimeters (Fig. 9). This part of the Third bone bed can hardly have originated other than by sweeping of coarse and fine particles over a mud-cracked surface, probably by wind, the finer particles being mostly by-passed. In this connection, the following quotation from Field (1928, p. 243–244) is pertinent:

"The surfaces of the smaller islands [on the Great Bahama Bank] are everywhere covered with several inches of sediment which appear to have been left by the subsiding waters (after hurricanes)

of the lagoon. This fine calcareous mud is covered with dessication fractures for many square miles. These fractures are . . . in places being preserved by a filling of relatively coarse fragments of shells."

Figure 10 shows schematically the postulated conditions surrounding the origin of the Third bone bed in the neighborhood of Locality 8. In Figure 10A a local

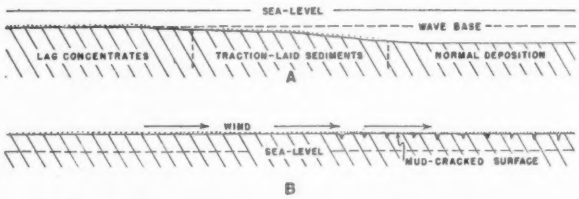


FIGURE 10. *Conditions of accumulation of Third bone bed*

A, first stage: formation of lag concentrates, traction-laid deposits, and normal basinward deposits; B, second stage: uplift, desiccation of limy muds, aeolian transportation and re-deposition of lag concentrates and traction-laid deposits.

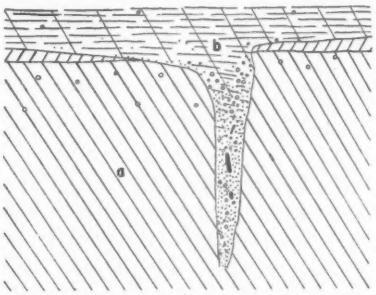


FIGURE 11. *Second bone bed at north end of Hobo quarry, Franklin County (Locality 4)*

a,—slightly crinoidal, massive, blue-gray lime-stone, the uppermost bed of Columbus formation, with thin gray band (pre-Delaware exposure?); b,—brown, shaly limestone with scattered bone material at bottom, the lowest bed of the Delaware formation. Note bone bed material filling desiccation crack in the Columbus. ×1.

arching of the sea bottom is presumed to have brought it to or slightly above the local wave base so that deposition of fine calcareous muds and small amounts of terrigenous material is not possible, but instead, lag concentrates of pelopsammic bone-bed material are formed Toward the right the bottom is represented as below the wave base, and normal deposition should occur. In Figure 10B the whole area is assumed to have been lifted above sea level. This exposes both the lag concentrates and the limy muds. The muds become cracked from desiccation under subaerial conditions and are covered with material swept from the patches of lag concentrates. The work of wind is suggested by the presence of well-rounded, frosted quartz grains.

Mud cracks seem to be filled by bone-bed material in the Second bone bed at the north end of the Hobo quarry, Locality 4 (Fig. 11), but this may have been accomplished by subaqueous transportation. The Third bone bed rests on a mud-cracked surface at other localities (nos. 13 and 14), and within it pebbles of the underlying

fine-grained limestone are found locally (Westgate and Fischer, 1933, p. 1170). The pebbles suggest an agency stronger than wind. Elsewhere, as in the Scioto quarry (Locality 7) and Delaware quarry (Locality 15), the stratum underlying the bone bed is even and not mud-cracked; the contact is either sharply defined by a very thin layer of brown shale or is wholly transitional. Where the base of the bone bed is

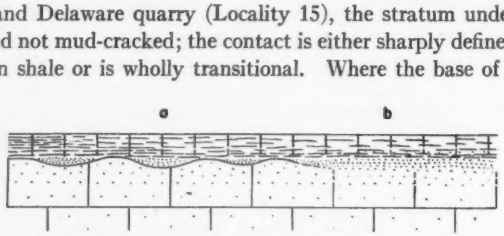


FIGURE 12. *Relations of Columbus formation (below), Second bone bed (dotted), and the Delaware formation (above) in Marble Cliff quarries group, Franklin County*

a,—lower contact of bone bed sharp and rolling; b,—bone bed gradational downwards.

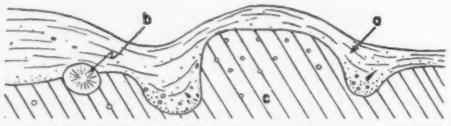


FIGURE 13. *Second bone bed at Marble Cliff Station (Locality 2)*

Resting with sharp lower contact on rolling top of Columbus formation. a,—shaly limestone with much bone material, especially in depressions; b,—zaphrentid coral; c,—crinoidal limestone with little bone material.

sharply defined, the deposit is interpreted as an accumulation of material washed out from lag concentrates formed on a near-by degradational bottom area above wave base. The somewhat coarse fragments were dropped within a short distance, whereas finer materials were by-passed to places farther basinward. Where the contact is gradational, the bone bed is interpreted as a lag concentrate formed on a degradational bottom area at or just above wave base. Without utilizing the concept of a degradational bottom area (the "eroding bottom" of ecologists) above wave base ("base level of deposition"), it is difficult to account for bone beds that are not sharply differentiated from the stratum on which or within which they lie, and it is equally difficult to explain the origin of similar lithotopes composed of aggregates resting with sharp lower contacts in shallow depressions or filling mud-cracked surfaces. The First bone bed at the only localities where it has been found thus far—in the Marble Cliff quarries (Locality 5) and at Locality 11—is completely transitional downward and is interpreted as a weakly developed lag concentrate formed during an interval when the aggradational sea bottom area that normally was receiving sediments was brought to the profile of equilibrium by a positive shift of the strand line to the west.

The Second bone bed is the most extensive of the central Ohio bone beds, and its relations and development differ from place to place. At most localities it has the appearance of a lag concentrate, as previously distinguished in the case of the First bone bed, but at a few places, such as the old quarry near Marble Cliff Station (Locality 2) and the north end of the Hobo quarry (Locality 4), it occurs in hollows of the top bed of the Columbus formation. The lower contact in some places is sharp (Figs. 12a, 13), but a few yards away it may be gradational (Fig. 12b), or the bone

bed may rest on a mud-cracked surface (Fig. 11). In the hollows the bone bed is coarse and packed with fish and pelmatozoan detritus. It often grades upward into a brownish shale or a very shaly limestone that contains similar but very diffuse detritus and belongs to the lowest beds of the Delaware formation (Fig. 12b). In the first case, where the uneven surface is sharply developed, as shown in Westgate and Fischer's Figure 2 and in Figure 13 of this paper, the uneven surface may be interpreted as the result of relatively rapid uplift of the bottom well above wave base with rapid, even violent erosion, and with the lag concentrates having either been left in the hollows as residual aggregates, as at the north end of the Hobo quarry,[21] or swept into the hollows elsewhere, as at the old quarry near Marble Cliff Station.

The Fourth bed (Westgate and Fischer, 1933, p. 1162), near the top of the Delaware formation and known only in an old quarry (Locality 15) at Delaware, rests unconformably on the slightly beveled or channeled underlying beds, which have a relief of as much as 3 feet. Fish remains are most abundant in the lowest 1 or 2 inches but are relatively common throughout the remaining 4 feet of crinoidal limestones. There are no signs of ripple marks or cross-bedding. The diastem indicated here is of considerably greater magnitude than in the case of the lower bone beds, but it seems to be very local.

SUMMARY

(1) The central Ohio bone beds do not represent the catastrophic annihilation of endemic fish faunas, nor are they the result of normal accumulation of the remains of teeming hosts of marine fishes, nor are they simply the accumulation of coarse materials strewn over the sea floor. They have no single, uniform mode of origin.

(2) The bone beds are associated with diastems resulting from fluctuations with respect to wave base of the bottom of a very shallow sea. They represent in places lag concentrates, in others, rapid subaqueous accumulations of coarser material transported from areas of lag concentration with by-passing of finer particles, and in still others, aeolian deposits derived from subaerial exposures of lag concentrates.

(3) While the sea bottom remained below wave base as it did throughout most of Columbus-Delaware time, limy muds containing occasional fish remains and other fossils were normally deposited (Fig. 14c).

(4) During early Columbus time the bottom remained below wave base for long intervals, while dolomitic strata (Bellepoint member) accumulated. During the latter part of Columbus time (Klondike member), however, the bottom fluctuated nearer and nearer to the level of wave base, especially during the deposition of the uppermost 10 or 12 feet, when the bottom was occasionally wave-rippled. For at least one short period, the sea bottom was locally above wave base, in Franklin and

[21] Westgate and Fischer (1933, p. 1166) state that the bone bed is absent at this spot in the north end of the Hobo quarry. The exposure is perhaps better than when they studied it, and many of the depressions show patches of bone bed with gradational lower contacts; the 1-inch layer of calcareous brown shale above it contains abundant fish remains. Their remark that this uneven condition and absence of bone bed patches here as contrasted with the presence of bone bed material with sharp lower contacts in the hollows at the Marble Cliff Station locality across the Scioto river "show the the unevenness existed prior to the deposition of the bone bed" loses its force, and the transition from the Columbus to the Delaware is indicated as diastematic rather than disconformable.

Delaware counties, with resulting condensation and accumulation of a weak lag concentrate—the First bone bed.

(5) By the end of the deposition of the last Columbus stratum the bottom was at or above wave base over a very wide area so that lag concentrates were extensively developed, eroded, and redeposited, forming the Second bone bed. There is little

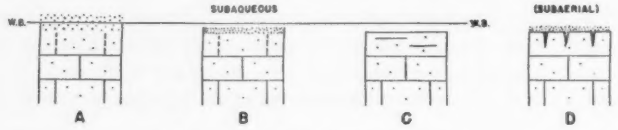


FIGURE 14. *Modes of bone-bed origin*

Under various conditions of bottom and wave base (W.B.) relations. A,—degradational bottom above wave base, with lag concentrates; B,—aggradational bottom barely below wave base receiving traction-laid coarse bone bed material, fine material being by-passed basinwards; C,—aggradational bottom well below wave base, receiving normal deposition; D,—conditions as in B, but with subaerial sorting and shifting of coarse materials.

evidence of any extensive subaerial exposure, erosion, or deposition at this time (Fig. 14a, b, c).

(6) The proximity of the bottom to wave base continued throughout much of Delaware time, but the relatively clear waters of the later Ulsterian in the Cincinnati arch region had given way to the muddier waters of Erian time as a result of accelerated uplift of Appalachia and the lowland of Cincinnatia. The absence of the Delaware and Olentangy formations in the Bellefontaine Devonian outlier, 50 miles northwest of the Franklin County outcrops, is very significant in this connection (Stauffer, 1909, p. 104). In this outlier the uppermost part of the Columbus formation, seemingly represented only by its lower units, is arenaceous, pyritiferous, and locally moderately rich in fish remains (East Liberty bone bed). Probably it represents conditions of accumulation similar to those of the Second bone bed, but with less aerated waters and probably much younger, perhaps late Erian (Olentangy)

(7) During the latter part of Delaware (early Erian) time, and probably at its close, there were intervals when the bottom was above wave base—hence the Third and Fourth bone beds. During the first of these diastems (Third bone bed), parts of the bottom were exposed to subaerial agencies (Fig. 14d). Areas east of Cincinnatia are visualized as having been broad, low flats of drying calcareous mud, here and there containing current-swept shallow channels and more or less stagnant pools.

(8) The proximity of the Columbus-Delaware bone beds to the geotropically positive Cincinnati arch suggests not only a genetic relation between them and this structure but also the reason for the absence of bone beds from the stratigraphic equivalents of these formations to the east in the Penn-York embayment and to the north in Michigan and Ontario (Onondaga-Hamilton), where the sea bottom rarely attained wave base for more than brief intervals. The presence of bone beds in Middle Devonian rocks west of the arch in Indiana (Rocky Branch bone bed) and south and east of it in Kentucky (Kiddville bone bed) strengthens this idea of relationship. Further, the feeble development of the only bone bed traceable northward from central Ohio, the Second, in northern Ohio indicates that the bottom was

only occasionally above wave base off the northern coast of Cincinnatia during the Ulsterian and Erian.

OHIO BONE BED LOCALITIES

(Numbers are those used in text and figure references)

1. Arlington, Franklin County. O.S.U. No. 3818, probably one of now-abandoned quarries near Marble Cliff Station. Second bone bed.
2. Marble Cliff Station, Franklin County. Abandoned quarry just northeast of station. Second bone bed. (Stauffer, 1909, p. 44).
3. Hobo quarry of Marble Cliff Quarries Co., west side of Scioto River across from Marble Cliff Station, Franklin County. West wall of quarry. First bone bed. (Stout, 1942, p. 213).
4. Same locality. West and north wall of quarry. Second bone bed.
5. Scioto quarry (Main or North quarry) of Marble Cliff Quarries Co., north of Hobo quarry. Along west wall of quarry. First bone bed. (Stout, 1942, p. 215).
6. Same locality. Second bone bed.
7. Same locality. Third bone bed.
8. Junction of McCoy Road and Scioto River Road, east side of Scioto River, 1 mile north of Fishinger bridge, Franklin County. Roadside exposure. Third bone bed.
9. J. and L. Snouffer quarry, east side of Scioto River, 1 mile south of Dublin road, Franklin County. East wall of quarry. Second bone bed.
10. Bartholomew run, west side of Olentangy River, Delaware County. Exposure in bed of creek at elevation 815 feet. Third bone bed. (Stauffer, 1909, p. 76).
11. Miami Stone Co. quarry, west side of Olentangy River, 2 miles north of Bartholomew run, Delaware County. Top of exposure in lower, now abandoned quarry. First bone bed.
12. Same. Near top of exposure at east end of south wall of upper quarry. Third bone bed.

12a. Deep run, east side of Olentangy River, 2½ miles north of Delaware-Franklin County line, Delaware County. Third bone bed. (Stauffer, 1909, p. 79).

13. Case run, east side of Olentangy River, Delaware County. One quarter mile up run from river. Third bone bed. (Stauffer, 1909, p. 80.)
14. Old quarry just north of abandoned schoolhouse, west side of Olentangy River, 1 mile north of Stratford, Delaware County. Top of exposure. Third bone bed. (Stauffer, 1909, p. 85).
15. Old quarry just west of Hocking Valley R.R. on Delaware run, Delaware, Delaware County. East wall of quarry. Third and Fourth bone beds. (Westgate and Fischer, 1933, p. 1162.)
16. Abandoned quarries just east of Owen, 5 miles southwest of Marion, Marion County. Near top of exposure along east side of quarry north of road. Second bone bed. (Stauffer, 1909, p. 92.)
17. J. M. Hamilton and Sons quarry, east of highway, 1¾ miles north of Marion, Marion County. Near top of exposure, west wall. Second bone bed.
18. National Lime and Stone Co. quarry on Broken Sword Creek, 1 mile northwest of Spore, about 6 miles northwest of Bucyrus, Crawford County. East wall, near top of exposure. Second bone bed. (Stauffer, 1909, p. 109.)
19. France Stone Co. quarry 1½ miles east of Bloomville, Seneca County. Floor, west end of north quarry. Second bone bed. (Stauffer, 1909, p. 110.)
20. Abandoned quarry 2 miles south of Venice at end of R. R. spur, Erie County. Above coral zone along east wall. Second bone bed. (Stauffer, 1909, p. 129.)
21. Abandoned quarry (Wagner No. 2 or Schoepfle) in southeast part of city of Sandusky, Erie County. Second bone bed. (Stauffer, 1909, p. 124.)

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The Ohio State University, Columbus, Ohio.

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EXPLANATION OF PLATE 1
BONE-BED LITHOLOGY

All figures are from thin sections oriented transversely to bedding, enlarged 6×.

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1. Second Ohio bone bed, top of Columbus formation, near Marble Cliff station, Franklin County, central Ohio. Black areas = bone, scales, and teeth; dark-gray areas = pelmatozoan fragments; light-gray linear areas = brachiopod fragments..... 281
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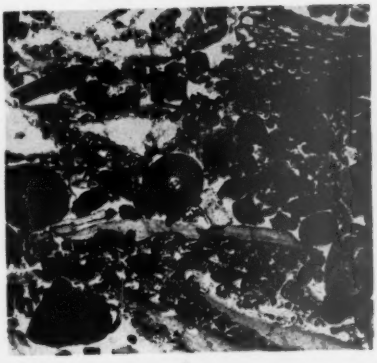

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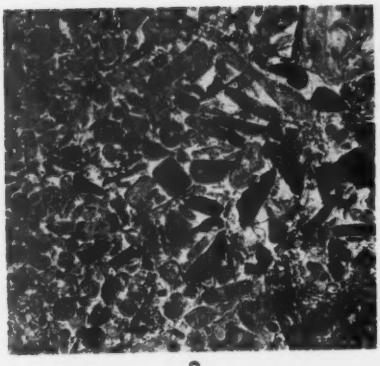

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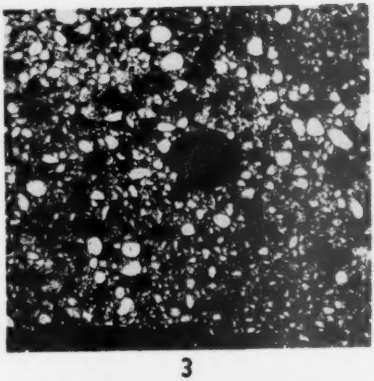

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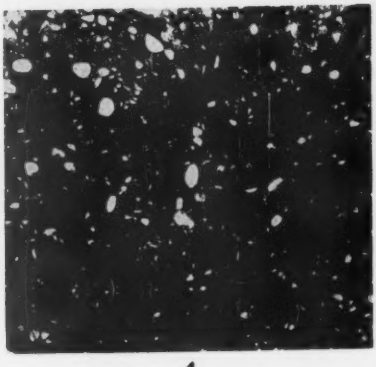

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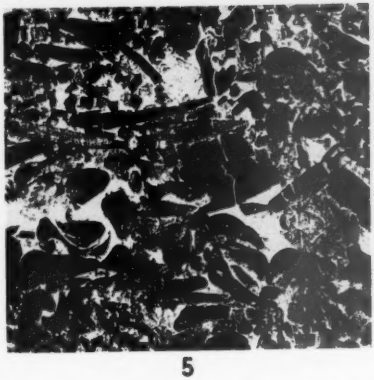

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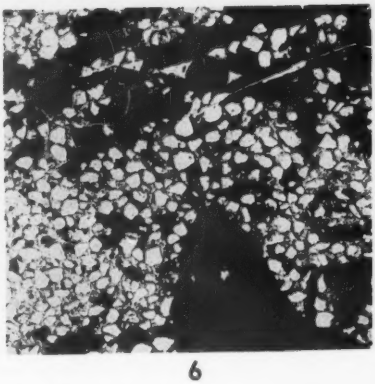

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BONE-BED LITHOLOGY

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PALEOZOIC STRATIGRAPHY OF THE SAWATCH RANGE, COLORADO

BY J. HARLAN JOHNSON

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ABSTRACT

The Sawatch Range, a high and rugged mountain uplift in central Colorado, separates the Arkansas River valley from the plateau region to the west. It includes some of the highest peaks in Colorado, with summit elevations around 14,400 feet. Very little of the region lies below 9000 feet.

The rocks range from pre-Cambrian to Recent but consist mainly of pre-Cambrian granite and metamorphics and Paleozoic sedimentary rocks. All are cut by Tertiary intrusives.

The Paleozoic sedimentary rocks represent every period except the Silurian. The Cambrian system is represented by the Sawatch quartzite, which attains considerable thickness locally and can be roughly subdivided into four members. The Ordovician rocks include three formations—the Manitou dolomite, Harding sandstone, and Fremont limestone. The Manitou, consisting of more or less siliceous dolomite and dolomitic limestone, is widespread and varies greatly in thickness. The Harding sandstone, represented by quartzite in part of the area, is thin and found only along the southern end of the range and along Cement Creek. The Fremont limestone is predominantly fossiliferous dolomite and is found only in the southern part of the Sawarch Range province. Unconformities occur at the top of each of the Ordovician formations, and the formations thin or wedge out to the north. The Devonian sedimentary rocks included in the Chaffee formation are widespread and include the shaly or sandy Parting member below and the Dyer dolomite member above. The Devonian sediments are discussed at length as many new data are presented. The Leadville limestone of Mississippian age unconformably overlies the Chaffee and is an important ore-bearing formation at Aspen and in other mining districts along the range. Another unconformity separates the Leadville from the Pennsylvanian Weber (?) formation above. The latter generally consists of shales in the lower parts, above which is a series of limestones and shales, overlain by sandy shales or sandstones. These beds grade upward into a series of red sandstones, grits, and conglomerates with some interbedded limestones, known as the Maroon formation, which includes both Pennsylvanian and Permian deposits. At present the boundary between the Pennsylvanian and Permian beds of this region has not been definitely drawn on either lithologic composition or color. The lower beds contain abundant fossils, but fossils become scarcer at higher stratigraphic positions. The information available suggests that the Pennsylvanian series may be 2000 to 2500 feet thick.

Devonian fish fragments were obtained from the lower member of the Chaffee including the basal layers. A coral fauna, obtained from the upper Leadville limestone at several localities, suggests the presence of some Mississippian beds younger than those hitherto reported. Structures suggesting growths of calcareous algae were noted in the Manitou and the Chaffee, and well-preserved fossil algae were obtained from the upper Leadville limestone and lower Weber (?) formation.

The paper includes 24 measured sections.

INTRODUCTION AND ACKNOWLEDGMENTS

The region along the west side of the Sawatch uplift has been little studied by geologists. The Hayden Survey (Peale *et al.*, 1876) made a rapid reconnaissance from 1872 to 1874. In 1894, Eldridge studied the Crested Butte quadrangle and published the only stratigraphic information available for nearly a generation on the region around the southern end of the Sawatch Range. In 1913 Crawford published his report on the Monarch and Tomichi district, which was followed shortly by a report on the Gold Brick district (Crawford and Worcester, 1916). Spurr (1898) studied some of the area in connection with his work at Aspen and published a detailed report. Mining engineers made detailed studies on properties around Aspen and prospects along the range but published only short notes. Stark and others have described the structure and pre-Cambrian geology of some portions of the region (1932; 1934).

Most stratigraphic information of the earlier writers was quite generalized, but during the last 40 years much has been learned of the stratigraphy of central Colorado, permitting closer correlations and finer stratigraphic subdivisions.

The Federal Geological Survey and the State of Colorado have recently cooperated in studying the stratigraphy and structure.

The present report is based on field work by the writer during 1931 and 1934, which consisted of measuring stratigraphic sections, tracing beds from one section

to another, and searching for fossils. The field work was supplemented by a laboratory study of the rock specimens and fossils collected. Some stratigraphic results of field work in the Aspen district during 1937 are also included.

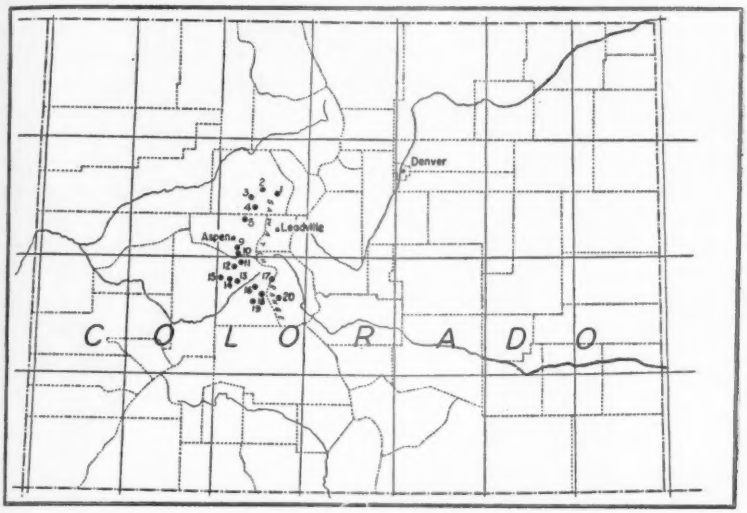
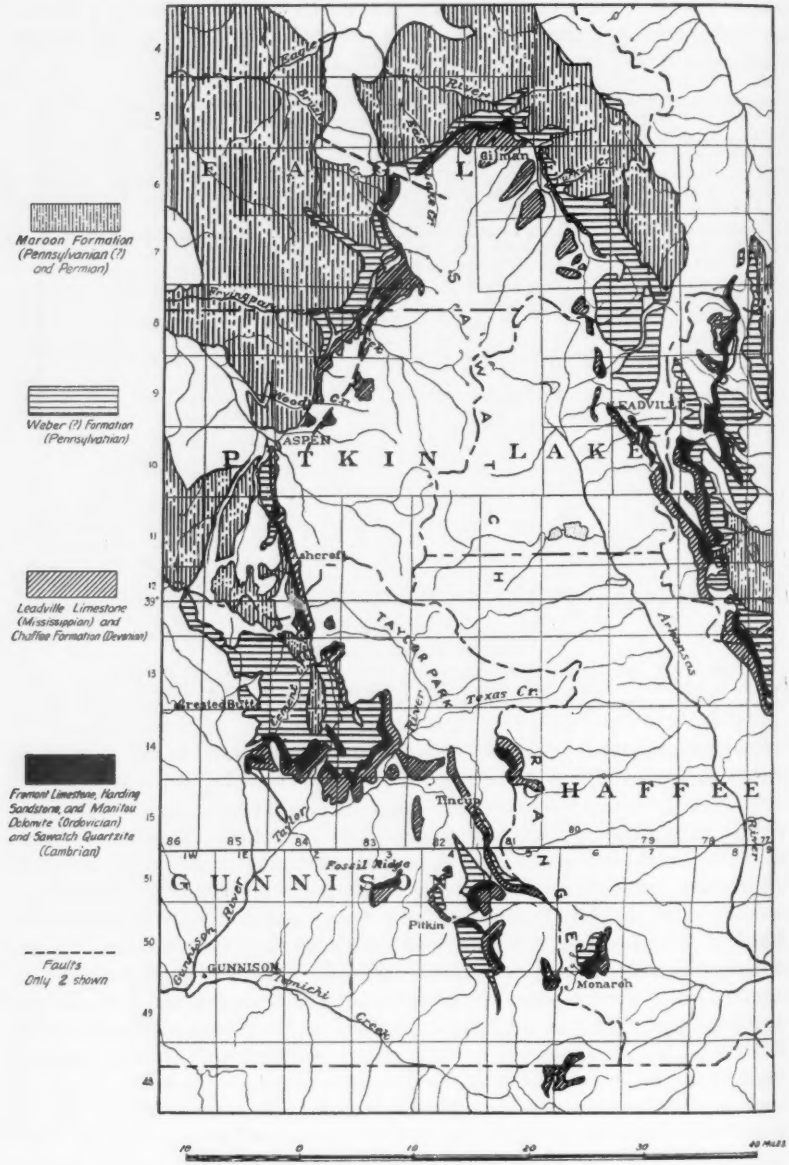


FIGURE 1.—*Index map of Colorado*
Showing location of sections.

1. Gilman, 2. East Lake Creek, 3. Brush Creek, 4. Wood's Lake, 5. Frying Pan River, 9. Ashcroft, 10. Taylor Pass, 11. Mount Tilton, 12. No. Italian Mountain, 13. Deadman's Creek, 14. Cement Creek No. 1, 15. Cement Creek, No. 2, 16. Cross Mountain, 17. Round Mountain, 18. Tincup, 19. Fossil Ridge, 20. Monarch.

This paper records new information on the stratigraphy, together with a summary of older material. The parts dealing with the pre-Pennsylvanian formations are fairly detailed, whereas those on the Pennsylvanian and Permian are relatively brief, as field study of these formations has not been completed. Moreover, the pre-Pennsylvanian deposits are of more immediate importance to the mining industry.

The writer gratefully acknowledges the information and the many courtesies extended by members of the Federal Geological Survey and by other geologists. C. H. Behre, Jr., T. S. Lovering, and W. S. Burbank visited parts of the area and assisted in interpreting some structural problems. John W. Vanderwilt suggested some interpretations of the Devonian-Mississippian contact at Aspen, and J. P. Rolfing contributed information on the same district. G. F. Loughlin, B. S. Butler, and J. B. Beeside, Jr., contributed from their general knowledge of Colorado geology. David White, G. H. Girty, and Edwin Kirk have helped greatly with the study of fossils and their interpretations. W. L. Bryant of Providence, Rhode Island, studied the fossil fishes, B. F. Howell assisted in interpreting the Cambrian rocks, and Rudolf Ruedemann identified the graptolites. John G. Bartram made valuable suggestions on some of the correlations. Most of the photographs of specimens were taken by Hugo Rodeck of the Natural History Museum of the University of Colorado.


Maroon Formation (Pennsylvanian (?) and Permian)
Weber (?) Formation (Pennsylvanian)
Leadville Limestone (Mississippian) and Chaffee Formation (Devonian)
Fremont Limestone, Harding Sandstone, and Manitou Dolomite (Ordovician) and Sawatch Quartzite (Cambrian)
Faults Only 2 shown
EAGLE
PITKIN
LAKE
CHAFFEE
GUNNISON
ASPEN
LEADVILLE
Tincup
Pitkin
Monarch
GUNNISON
Fossil Ridge
Taylor River
Texas Cr.
Arkansas
Fryingpan
Roaring Fork
Eagle
Gunnison River
Tomichi
Cement
Mt. Elbert
Mt. Massive
Mt. Harvard
Mt. Yale
Mt. Princeton
Mt. Antero
Mt. Shavano
Mt. Ouray
Mt. Aetna
Mt. Hunter
Mt. Belford
Mt. Oxford
Mt. Columbia
Mt. Huron
Mt. Missouri
Mt. Sherman
Mt. Sheridan
Mt. Bross
Mt. Democrat
Mt. Lincoln
Mt. Cameron
Mt. Bartlett
Mt. Evans
Mt. Silverheels
Mt. Guyot
Mt. Powell
Mt. Zirkel
Mt. Wilson
Mt. Ellingwood
Mt. Adams
Mt. Lindsey
Mt. Blanca
Mt. Herard
Mt. Crestone
Mt. Lafayette
Mt. Crestone

STRUCTURE

The range is a great asymmetric fold of north-south trend, cut by numerous faults and widened and modified by intrusions. The deformation is related to the Laramide folding but has been modified by Tertiary intrusion and crustal movements. In general, the sedimentary rocks have been largely or entirely removed from the crest and the eastern flank of the mountains, but they are well exposed on the western side, except where erosion has cut so deeply over a large area that the crystalline rocks are exposed (Fig. 2). Usually the Paleozoic beds strike parallel to the present structural trend of the range.

Thrust faults occur along the flanks, and locally, as in the Aspen district and in Taylor Park, extensive normal and thrust faulting has occurred. The general sequence of structural events appears to have been folding, thrust faulting, intrusion, and normal faulting. The structure is most complex in the Aspen district and around Taylor Park (Stark, 1934; Vanderwilt, 1935a), where faulting and intrusion were most active. Stark has described thrust faults in the Tincup-Graphite basin, near Biglow along the Frying Pan River, and along East Lake Creek (Stark, 1934, p. 1004–1014).

STRATIGRAPHY

GENERAL STATEMENT

The rocks of the Sawatch Range province range from pre-Cambrian to Recent but consist mainly of pre-Cambrian crystalline and Paleozoic sedimentary rocks, with some Tertiary intrusives and glacial and stream deposits.

The Paleozoic formations include deposits of every period except the Silurian. However, several unconformities occur within the section, some of which represent long time intervals for which deposits are lacking.

Table 1 summarizes the characteristics of the formations; Table 2 gives the thicknesses of the Paleozoic formations in the sections measured.

UNCONFORMITIES

The numerous unconformities show that erosion occurred at some time during the late pre-Cambrian and early and middle Cambrian, at several times during the Ordovician, at some time or times between the late Ordovician and late Devonian, during the later part of the Mississippian, at some time or times between the late Permian and Jurassic, in the late Jurassic and early Cretaceous, and from the end of the Cretaceous to the present (Tables 1, 2; stratigraphic sections). Of these, the unconformities beneath the Cambrian deposits, the late Devonian, and the late Mississippian, and those of post-Permian times were most important with regard to time and areas involved and amount of erosion (Lovering and Johnson, 1933). Very minor breaks occurred during the deposition of the Sawatch quartzite in late Cambrian time and in late Devonian Chaffee time; but these are considered intraformational breaks of small time and areal extent.

The unconformities between the Paleozoic formations appear to have resulted from recessions and advances of the sea rather than local crustal movements, as the formations have essentially conformable bedding.

TABLE 1.—*General stratigraphic column of the Sawatch Range, Colorado*

Age	*Formation*	*Thickness (Feet)*	*Lithologic character*
Pleistocene	Unconformity		Moraines, gravel, silts, and torrential fans.
Tertiary			Volcanic rocks, mainly intrusive but some extrusive. Some silts. Scattered patches of Tertiary tillites along Taylor Park and near Gunnison.
Permian and Pennsylvanian (?)	Unconformity Maroon formation	8000–13,000	Sandstones and sandy shales with many beds and lenses of conglomerate. A few limestones. Usually red, but gray and brown layers not uncommon.
Pennsylvanian	Weber (?) formation	400–600	Gray sandstones, sandy shales, shales, and limestones, which become coarser and more arkosic toward top. Black shales with thin impure limestones, sandy shales, and dark-gray sandstones near base.
Mississippian	Unconformity Leadville limestone	0–225	Dolomite, dolomitic limestone, and limestone. Blue gray to lead gray. Beds massive to thin. Contain thin breaks of shale or sandy material. Layers of depositional breccia, especially toward southern end of range. Chert nodules and streaks are locally abundant, especially at northern end of range. Basal layer is a sandstone overlain by a depositional breccia of limestone fragments in a sandy calcareous matrix.
Upper Devonian	Unconformity Chaffee formation		*Dyer dolomite member:* Dolomitic limestones, light to dark gray. Bedding thin to medium. These grade downward into lower member. *Parting member:* Sandstones and sandy shales with heavy basal sandstones and congomerate at northern end of range. South of the Roaring Fork River the member consists largely of shales, calcareous mudstones, sandy shales, and thin sandstones, light yellow or yellow green.
Upper Ordovician	Unconformity Fremont limestone	0–65	Dolomite, dark gray, massively bedded. Not present along range north of Taylor Park.
Middle Ordovician	Unconformity Harding sandstone	0–14	Sandstone or quartzite, locally slightly calcareous. White, brown, purple, or red; usually a dark purplish red. Present only in southern third of area.
Lower Ordovician	Unconformity Manitou dolomite	100–370	Thinly bedded dolomites and dolomitic limestone. Very siliceous in places. Limestone nodules and streaks of light-colored cherts common in upper half. White to light gray along northern end of range, becoming darker at south.

TABLE 1.—*Continued*

Age	*Formation*	*Thickness (Feet)*	*Lithologic character*
Upper Cambrian	Unconformity in some localities Sawatch quartzite	0–80	Shales, thin limestones, shaly limestones, and sandy shales form an upper transition member (Peerless shale) at most localities but not everywhere present.
Upper Cambrian	Sawatch quartzite	118–300	Quartzite, usually white, but locally brown. Upper half may contain streaks of greensand. Usually a basal conglomerate. Bedding medium to massive.
Pre-Cambrian	Unconformity		Gneiss, schist, and granite. All cut by pegmatite dikes.

TABLE 2.—*Thicknesses of formations in sections along the Sawatch Range*

	Sawatch quartzite	Manitou limestone	Harding sandstone	Fremont limestone	Chaffee formation			Leadville limestone
					Undivided	Parting sandstone member	Dyer dolomite member	
Gilman	220	72			118	40	78	125
East Lake Creek	235	39			200	79	121	68
Brush Creek	292	62			242	98	144	24
Woods' Lake	161	131			203	72	131	174
Frying Pan River	202	117			24	24		0
Smuggler Mountain	180	165			230	55	175	0
Aspen Mountain	200	237			274	49	225	119
Tourtelette Park	327	312			303	53	250	103
Richmond Hill	400	375						
Ashcroft	236	370			142			
Taylor Pass	188	223			118			
Mt. Tilton	137	273		14	147			92
Italian Mountain	273	346		?	223			13
Deadman Creek	258	218		65	180			89
Cement Creek 1	264	183		40	213			160
Cement Creek 2	300	178	12	38	386			81
Cross Mountain	347	200	5	32	210			56
Round Mountain	137	99	7	28				252
Tincup								
Fossil Ridge	119	212	10	35–38	529			224

CAMBRIAN SYSTEM

Sawatch quartzite.—The Cambrian Sawatch quartzite crops out along the west side of the Sawatch Range and along the southern and western sides of Taylor Park (Fig. 3; Pl. 1). In many places the quartzites form cliffs along the hillsides and canyon walls.

NOMENCLATURE AND DISTRIBUTION: Eldridge (1894, p. 6) gave the name "Sawatch quartzite" to the Cambrian deposits in the Crested Butte quadrangle and in other parts of the region flanking the Sawatch Range on the west. Later geologists have used the same term to include all the Cambrian rocks of central Colorado.

TABLE 3.—*Subdivisions of the Sawatch quartzite recognized by previous writers in central Colorado*

Eldridge (1894, p. 6) Anthracite-Crested Butte area		Spurr (1898, p. 4–7) Aspen district	Behre (1932, p. 58) Weston Pass district	Johnson (1934, p. 18–20) Mosquito Range	Vanderwilt (1935a, p. 444) Yule Creek
Upper	Red or brown impure quartzite	Transitional sandy-dolomite Glauconitic grit Dolomitic quartzite	Peerless shale member	Peerless shale	Quartzite, limestone, dolomitic limestone, & shales
Lower	White quartzite	Thick series of white quartzites with basal conglomerate	White quartzite member	Quartzite member	Quartzite gray and fine-grained

TABLE 4.—*Subdivisions of the Sawatch quartzite along the Sawatch Range*

Sawatch quartzite	Peerless shale member (4)	"Transition beds." Shales, sandy shales, calcareous shales, and thin limestones
	Upper quartzite member (3)	White quartzites
	Glauconitic sandstone member (2)	Red and brown sandstones or quartzites; glauconite beds and streaks abundant. Some beds may be quite calcareous
	Lower quartzite member (1)	White quartzites with the basal beds composed of conglomerate or coarse sandstones that are usually arkosic

LITHOLOGIC CHARACTERISTICS AND THICKNESS: Previous workers in central Colorado have recognized at least two divisions in the Sawatch quartzite, as shown in Table 3. The writer has recognized four subdivisions in the Sawatch area (Pl. 1); they are best developed around Taylor Park (Fig. 3; Pl. 1).

All members of the Sawatch quartzite show considerable range in thickness and are not present in all measured sections. At most localities gradation from one member into the next may be seen. However, in places there are indications of breaks in deposition and even erosion between the several members. In some sections entire members are absent.

Although members are most strongly defined around Taylor Park and northward to the Roaring Fork River, their presence is suggested by the stratigraphic sequence all along the Sawatch Range. Figure 3 and Plate 1 show their development and distribution.

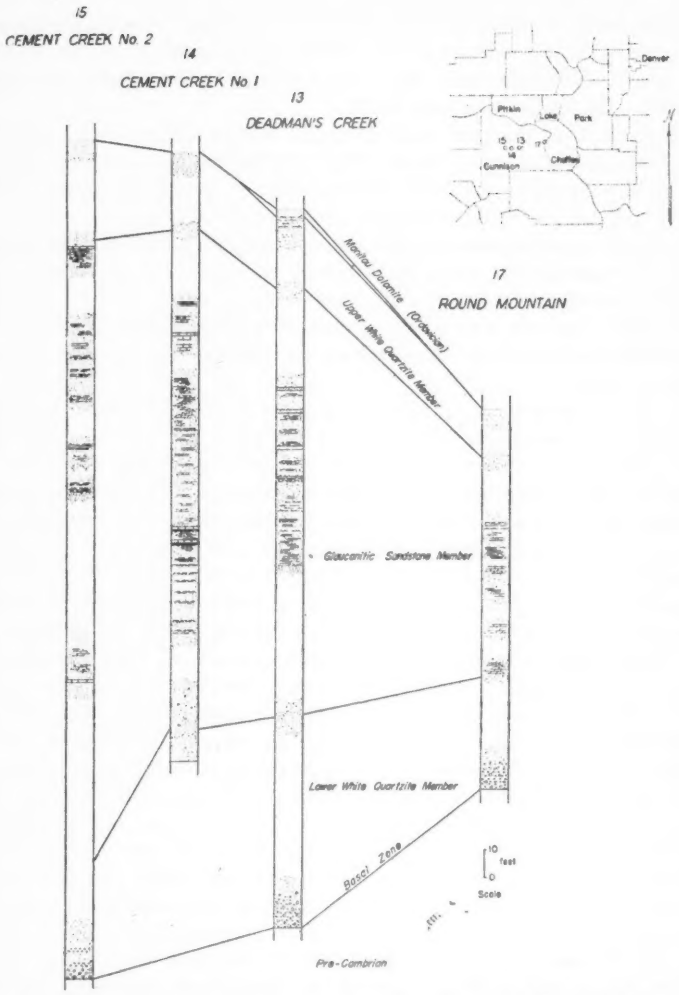


FIGURE 3.—*Sections of Cambrian deposits across the south end of Taylor Park*

The Sawatch quartzite rests directly upon the eroded surface of the pre-Cambrian rocks. The contact from Gilman to Brush Creek is clean-cut (Pl. 3, fig. 2); a thick basal conglomerate of well-rounded pebbles rests on a relatively smooth surface of pre-Cambrian granitic rocks. Farther south, in the Aspen district, the pre-Cambrian granite was deeply weathered before the deposition of the Cambrian beds so that the lower beds of the Sawatch consist of arkosic grit only slightly reworked before deposition. Under these conditions the exact boundary between the granite and the Cambrian is difficult to distinguish within 1 or 2 feet (Pl. 3, fig. 1).

Still farther south between Pitkin and Mosca the contact is well defined by a basal conglomerate of well-rounded quartz pebbles in an arkosic groundmass cemented with quartz. The basal beds, only a few feet thick, grade upward into the white quartzite. No fossils have been found.

The change from the basal conglomerate to this quartzite zone is usually gradational through several feet of arkosic beds, which gradually become finer-grained and less arkosic upward to the nearly pure quartzites. At a few localities the coarse arkosic conglomerate changes abruptly to fine-grained quartzite.

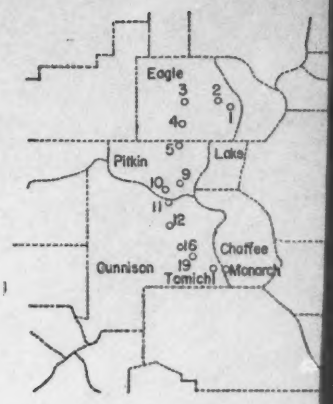
Above the basal conglomeratic and arkosic beds is a sequence of white quartzites, usually fine-grained with rather massive bedding. At all the localities studied the quartzite is well cemented and a pronounced cliff maker.

The white quartzite zone usually grades upward and interfingers with a brown calcareous zone forming the base of the second member, although in some places the change is sharp.

The lower quartzite member ranges from about 30 to 100 feet thick (Fig. 3; Pl. 1). No fossils have been found. The member next above the lower quartzite member is the glauconitic sandstone member. It consists of gray, brown, red, and black quartzites; gray, brown, and pink sandstones; green to black glauconitic sandstones; calcareous sandstone; thin impure limestones; and calcareous sandy shale. Some beds, especially the glauconitic sandstones, are quite arkosic with abundant fine fragments of feldspar and mica. Mica flakes occur on many bedding planes. The glauconite occurs as thin streaks and lenses and in the depressions of ripple-marked surfaces. The bedding is extremely variable, ranging from a few inches to several feet thick. Many bedding planes are ripple-marked and show abundant fucoid casts. Some sandstones contain numerous worm borings. The beds show considerable range in hardness and resistance to weathering and erosion. The outcrops are commonly stained dark. The variable bedding, ripple marks, fucoids, glauconite streaks and lenses, and arkose all point to deposition in shallow water close to land.

The glauconitic sandstone member is thickest and contains the coarsest material along the lower part of Cement Creek in the southeastern part of the Crested-Butte quadrangle (Fig. 3). To the north, it grades into white quartzite as white beds gradually appear between the dark ones and become thicker and more numerous toward the north end of the range. South and east of Cement Creek there are suggestions of an erosional break as the uppermost Peerless shale member of the formation rests directly upon these glauconitic sandstone beds, which at the same time become thinner (Fig. 3; Pl. 1). Near Taylor Pass definite channeling was observed at the top of member 2, with member 4 resting above it. No identifiable fossils were obtained from member 2.

In many of the sections studied another series of white quartzites is above the glauconitic sandstone member. Normally, it includes thin to massively bedded quartzites which usually form cliffs. This member attains its greatest thickness of 150 feet at Gilman at the extreme northern end of the range and thins southward until it is practically absent between Ashcroft and Mount Tilton. South of Mount Tilton it reappears, gradually thickens (Pl. 1) southward to Fossil Ridge, and then thins and disappears under an unconformity.



1
GILMAN

3
BRUSH CREEK

2
EAST LAKE CREEK

5
FRYING PAN RIVER
DEVIL'S CHIMNEY CAMP

9
ASHCROFT

4
WOOD'S LAKE

Manitou Dolomite

Manitou Dolomite
(Ordovician)

Peerless Shale
Member
(Transition Zone)

Upper
White
Quartzite
Member

Upper White
Quartzite Member

Glauconitic
Sandstone
Member

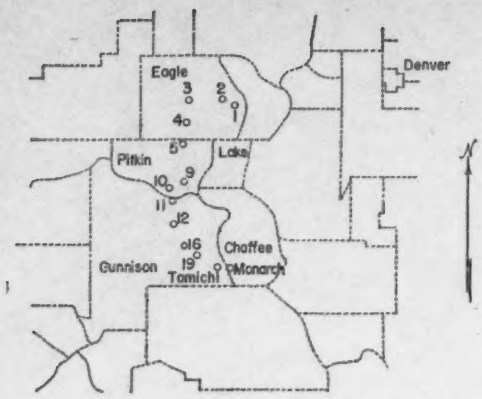
Lower White
Quartzite Member

Basal Zone

Sawatch Quartzite

Pre-Cambrian

SECTIONS OF CAMBRIAN DEPOS



5
YING PAN RIVER
L'S CHIMNEY CAMP

9
ASHCROFT

10
TAYLOR PASS

11
MT. TILTON

12
NO. ITALIAN MOUNTAIN

16
CROSS MTN.

19
FOSSIL RIDGE

TOMICHI DISTRICT

MONARCH

Manitou Dolomite (Ordovician)

Peerless Shale Member (Transition Zone)

Upper White Quartzite Member

Glauconitic Sandstone Member

Lower White Quartzite Member

Basal Zone

Pre-Cambrian

Peerless Shale Member

Upper White Quartzite Mem.

Glauconitic Sandstone Member

Lower White Quartzite Member

Basal Zone

10 feet
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Scale

SECTIONS OF CAMBRIAN DEPOSITS SHOWING LITHOLOGIC ZONES

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Along the northern part of the range it apparently grades downward and interfingers with member 2. No fossils have been obtained.

The uppermost member, the Peerless shale member, includes beds that are transitional between the Sawatch quartzite and the Manitou limestone. It corresponds to

TABLE 5.—*Nomenclature used in earlier reports for Ordovician rocks of Central Colorado*

	Eldridge (1894, p. 6) Anthracite-Crested-Butte	Spurr (1898, p. 9–13) Aspen district	Crawford (1913, p. 56–60) Monarch District	Crawford and Worcester (1916, p. 53–54) Gold Brick District	Johnson (1934, p. 18, 21–23) Mosquito Range	Vanderwilt (1935a, p. 445–447) Yule Creek
Devonian				Upper Yule limestones	Parting member of Chaffee formation	Parting member of Chaffee formation
Ordovician Upper					Fremont limestone	Fremont limestone
Ordovician Middle	Yule limestone		Tomichi	Yule	Harding sandstone	Harding quartzite
Ordovician Lower	(Silurian)	Silurian beds	Limestone	Limestone	Manitou limestone	Manitou limestone

the Peerless member of the Sawatch quartzite of Weston Pass and other parts of the Mosquito Range (Behre, 1932; Johnson, 1934, p. 19). Lithologically, the member includes sandy shale, shaly sandstone, calcareous shale, impure limestone, and sandy dolomite, with a few beds of fine sandstone and even quartzite. Beds of edgewise conglomerate are present containing flat to slightly rounded pieces of sandstone and impure limestone in a sandy or calcareous matrix (Pl. 4, fig. 1). They range through gray, brown, chocolate, greenish gray to white, or creamy yellow. Near Taylor Pass dark-gray and even black shales and impure dolomite occur at the top.

The sandstones are ripple-marked in places. Many bedding planes show impressions and casts of fucoids. The bedding is usually thin. The member ranges from a few feet to almost 100 feet thick. It is absent along Cement Creek and at Fossil Ridge where the Manitou lies directly upon member 3.

At some localities along the Sawatch Range the Peerless shale member is quite fossiliferous and contains numerous small brachiopods and a few poorly preserved trilobite fragments. The following have been identified: *Lingulella sp.*, *Billingsella sp.*, *Saukia sp.*

Graptolites were obtained from black shales between dolomites near the top of the member in the Ashcroft and Taylor Pass section (Pl. 4, fig. 2). Dr. Rudolf Ruedemann (written communication, December 13, 1934), who identified the forms, states:

"The collection No. 2683 (from Bed 15, Ashcroft Section) contains:

Dictyonema sp.
Callograptus sp. nov.

The collection No. 2684 (Bed 33, Taylor Pass Section) contains:

Callograptus cf. *C. antiquus* Rued.
Dendrograptus hallianus (Hall)
Dictyonema n. sp.

"The material from 2683 is non-conclusive because no species was identified; the two species in 2684 that can be identified suggest the Upper Cambrian; *Callograptus antiquus* occurring in the Nolichucky shale (not Elbrook formation) and *Dendrograptus hallianus* in the Trempaleau formation of Minnesota."

CONDITIONS OF DEPOSITION: During much of the Cambrian period the Colorado region was subjected to weathering and erosion. About the middle of the Upper Cambrian epoch a sea gradually advanced and covered the Sawatch Range province. The first beds deposited in the sea were highly weathered materials from the pre-Cambrian rocks, but slightly reworked. Later, as the sea advanced and the waters deepened, the sediments became more thoroughly sorted; the particles were smaller, fragments of feldspar and mica were fewer; and quartz grains predominated. Gradually grains of dolomite and glauconite formed and mingled with the clastic sediments. Close to the shores deltas and bars of coarser arkosic material built out and interfingered with the pure, finer-grained sandstones of the sea bottom. At or near the close of the period the sea became shallow and small areas emerged above it. Fine silts were washed into the sea with fragments of the rocks previously deposited, forming beds of shale and edgewise conglomerate among the sandstones and sandy dolomites.

AGE: The only fossils in the Cambrian deposits along the Sawatch Range were from the upper member. C. E. Resser studied similar fossils from the Sawatch quartzite of the Mosquito Range and reported that they are undescribed species of brachiopods and trilobites. The trilobites belong to the genera *Tellerina*, *Saukia*, and *Briscoia* of family Dikellocephalidae, and the brachiopods are of the *Lingulella* or *Westonia* type (Johnson, 1934, p. 20). Although graptolites from beds in the upper part of the Peerless shale member at the southern end of the Aspen district are largely new species, they suggest late Cambrian types, according to Ruedemann (personal communication, December 15, 1934). The age indicated by the fossils is middle to late Cambrian.

ORDOVICIAN SYSTEM

General statement.—Along the Sawatch Range the Ordovician deposits include remnants of three distinct formations—the Manitou dolomite of lower Ordovician age, the Harding sandstone of Middle Ordovician age, and the Fremont limestone of Upper Ordovician age. Unconformities separate them in this area, and at the top of the Ordovician section a great unconformity represents the time interval from the late Ordovician until after the middle of the Devonian. Much of the Ordovician sediment originally deposited has been removed by erosion in the intervals represented by these unconformities. Most of the erosion was probably subaerial.

Along the southern end of the range all three formations are present. All three were noted from Monarch north to the Tincup district and on Cross Mountain to the west of Tincup. Farther west along Cement Creek and Deadman's Creek (eastern side of the Crested Butte quadrangle) one section shows all three, one shows

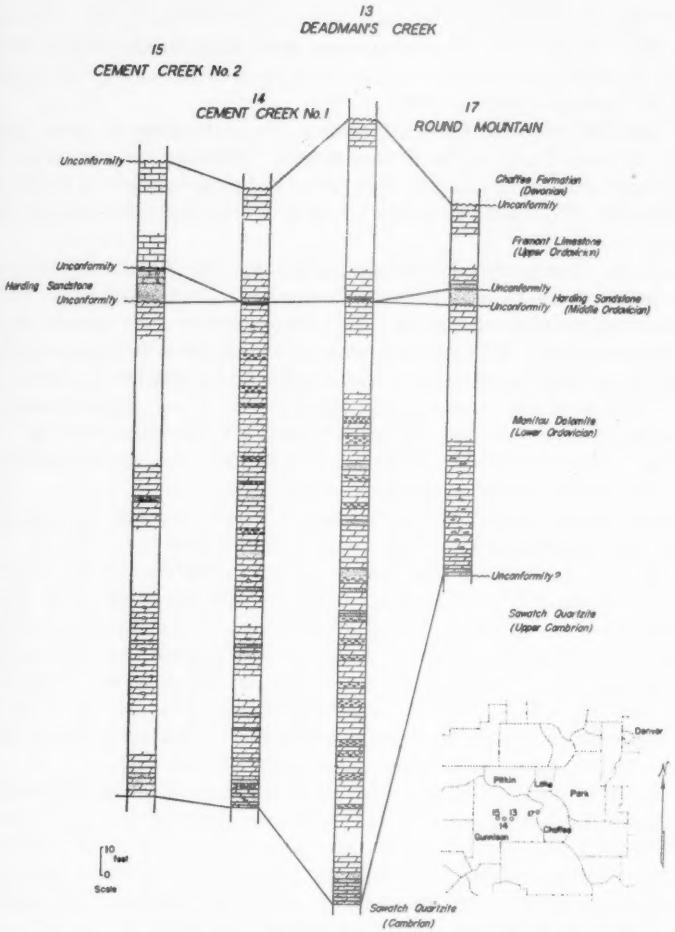


FIGURE 4.—*Sections of Ordovician formations across the south end of Taylor Park*

two of them, and the third section shows only one. North of Taylor Park only the Manitou dolomite is present, and it shows a wide range in thickness (Fig. 4; Pl. 2).

Manitou dolomite.—The Manitou dolomite is the most widespread Ordovician formation and attains the greatest thickness.

NOMENCLATURE AND DISTRIBUTION: Overlying the Sawatch quartzite is a series of dolomites, which Spurr (1898, p. 9) called the Silurian beds and which generally correspond to the middle division of the Yule limestone of Eldridge (1894, p. 6). Crawford (1913, p. 56–61) included it in the Tomichi limestone of the Monarch and Tomichi districts, and it formed the lower part of the Yule limestone as used by Crawford and Worcester (1916, p. 53–54) in the Gold Brick district. Along the

Mosquito Range the formation originally known as the White limestone (Emmons, 1886, p. 60) is for the most part the equivalent of the Manitou limestone of the Colorado Springs region, so it seems advisable to use the name Manitou for the formation in central Colorado (Johnson, 1934, p. 21).

The formation crops out along the western side of the range at many localities between Monarch Pass and the Tincup district. Outcrops are good along Fossil Ridge, along Cement Creek, and in fault blocks along the west side of Taylor Park. From Ashcroft (Pl. 2) northward they are fairly continuous to the northern end of the range.

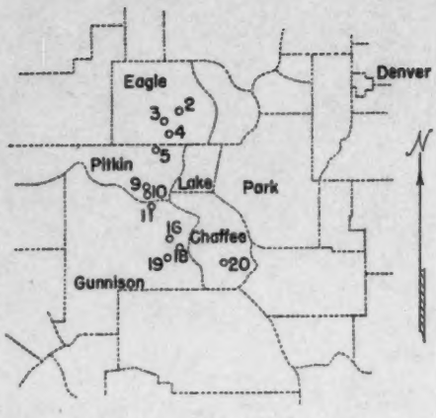
Lithologic Character and General Relations: The Manitou consists mainly of thin-bedded dolomite and dolomitic limestone which are usually quite siliceous. The limestones are finely crystalline. Thin breaks of shale occur between the dolomitic limestone beds. They are most noticeable in the lower portion of the formation but are probably more common than appears on the weathered surfaces (Pl. 7, fig. 1). In most places the bedding is thinnest at the base. Light-colored cherts are common at certain horizons, especially in the middle half of the formation. They appear as concretions and thin seams and, in a few localities, as tubular branching forms that strongly suggest a replacement of fucoids.

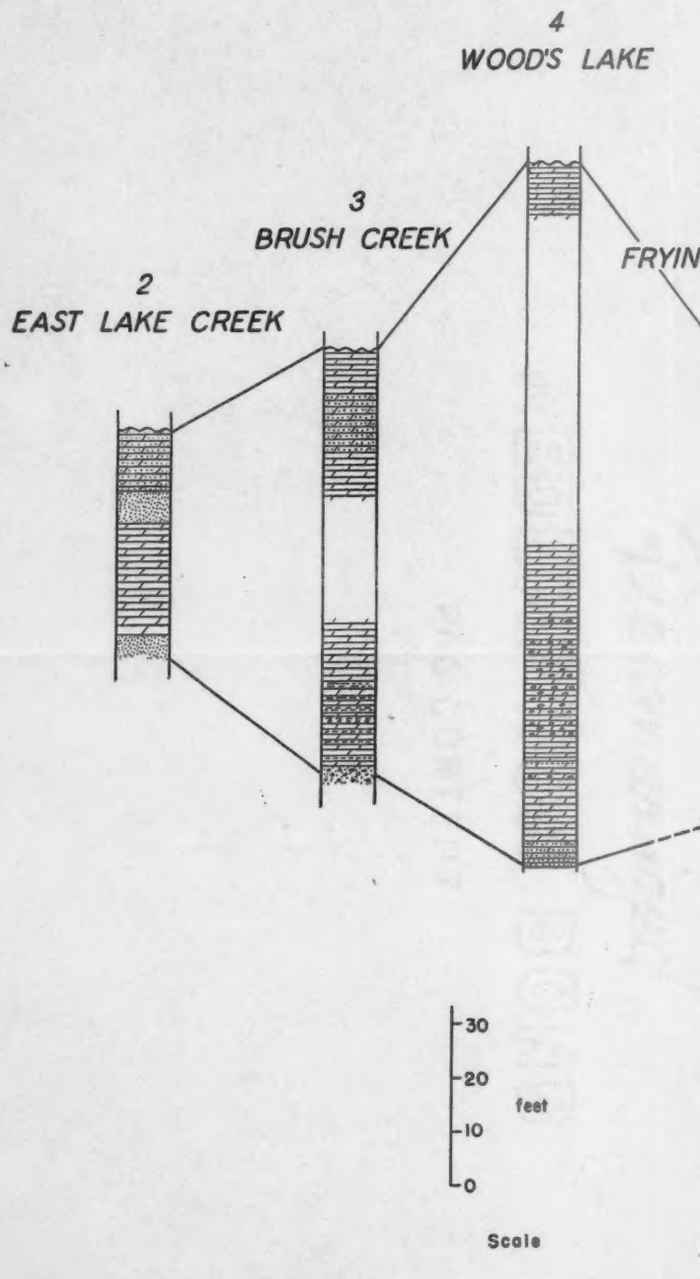
In many sections studied, deposition seems to have been almost continuous from Sawatch into Manitou time through a series of transitional beds. However, edgewise conglomerates and several intraformational unconformities may represent appreciable time breaks. At some localities at the southern end of the range there is a sharp stratigraphic break at the base of the Manitou. In the Monarch and Tomichi districts it rests on the pre-Cambrian granite or unconformably on thin remnants of Sawatch quartzite. An erosional unconformity was definitely seen along Cement Creek in sec. 14, T. 14 S., R. 85 W., where the Manitou dolomite rests on an irregularly eroded surface of the white Cambrian quartzite. The absence of the transition zone at some localities also indicates an important unconformity.

An unconformity also occurs at the top of the formation wherever studied, as shown by the great differences in thickness, the irregularity of the upper surface, the weathering and discoloration of the upper layer or layers, and the fact that the Manitou dolomite is overlain by different formations at different localities. In places Harding sandstone overlies it, elsewhere Fremont limestone, and at still other places the Chaffee formation is immediately above (Fig. 4; Pl. 2).

Local Features: In the Monarch and Tomichi districts the Manitou rests directly on the pre-Cambrian rocks in places. It is somewhat darker and more massive than elsewhere. For a few feet above the base the beds are quite sandy, and the limestones are not so dolomitic as they are higher up. Locally metamorphism has altered the sediments to a coarse white marble.

Along Fossil Ridge the Manitou dolomite comprises three lithologic units of about equal thickness that are well exposed in the cirque above Boulder Lake. The lower unit, 74 feet thick, consists of thin-bedded impure siliceous dolomites. Some beds are quite sandy, with large sand grains sprinkled through the dolomitic layers. A number of the bedding planes are prominently ripple-marked. Breaks of shale occur between most of the dolomite layers. Many beds appear quite porous as if


Eagle
Denver
Pitkin
Lake
Park
Chaffee
Gunnison
N


4
WOOD'S LAKE
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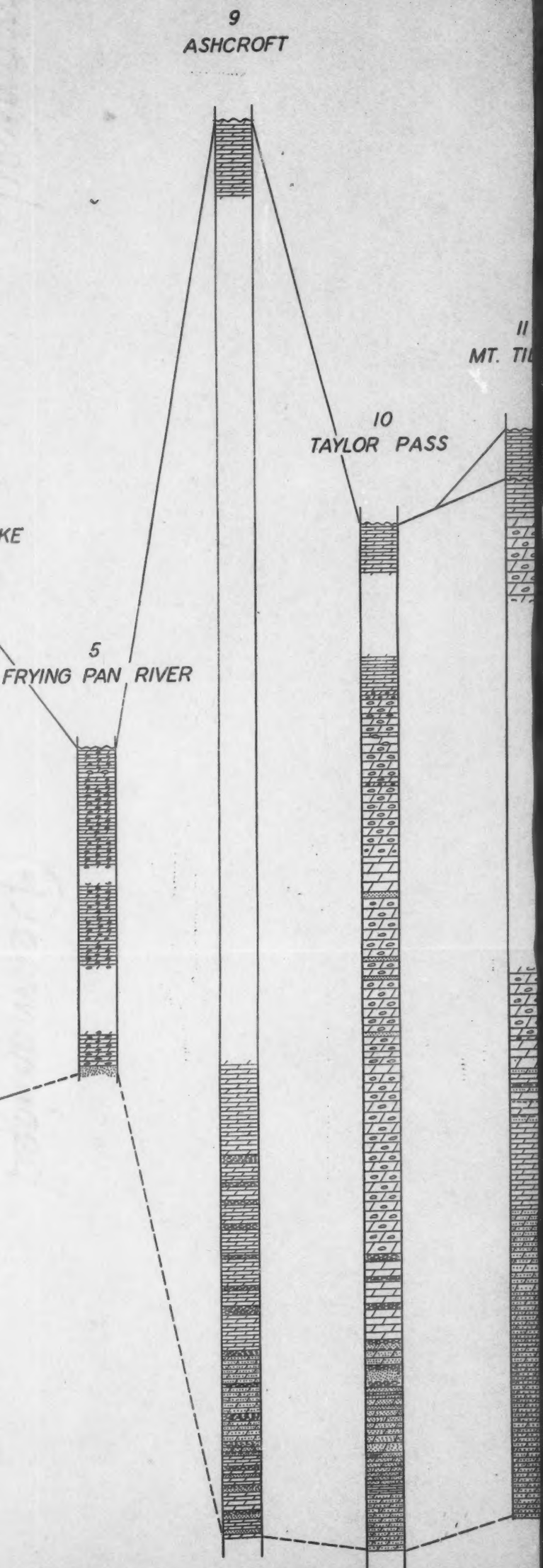
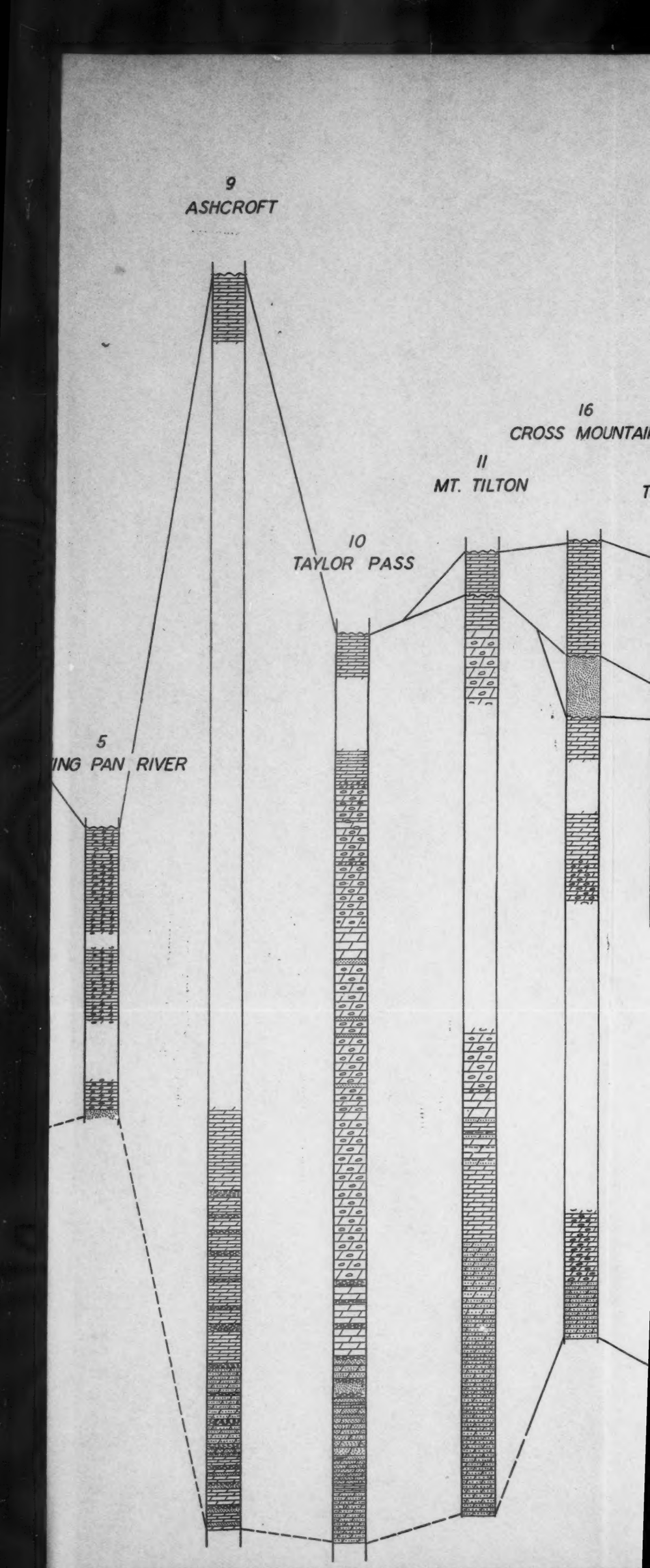
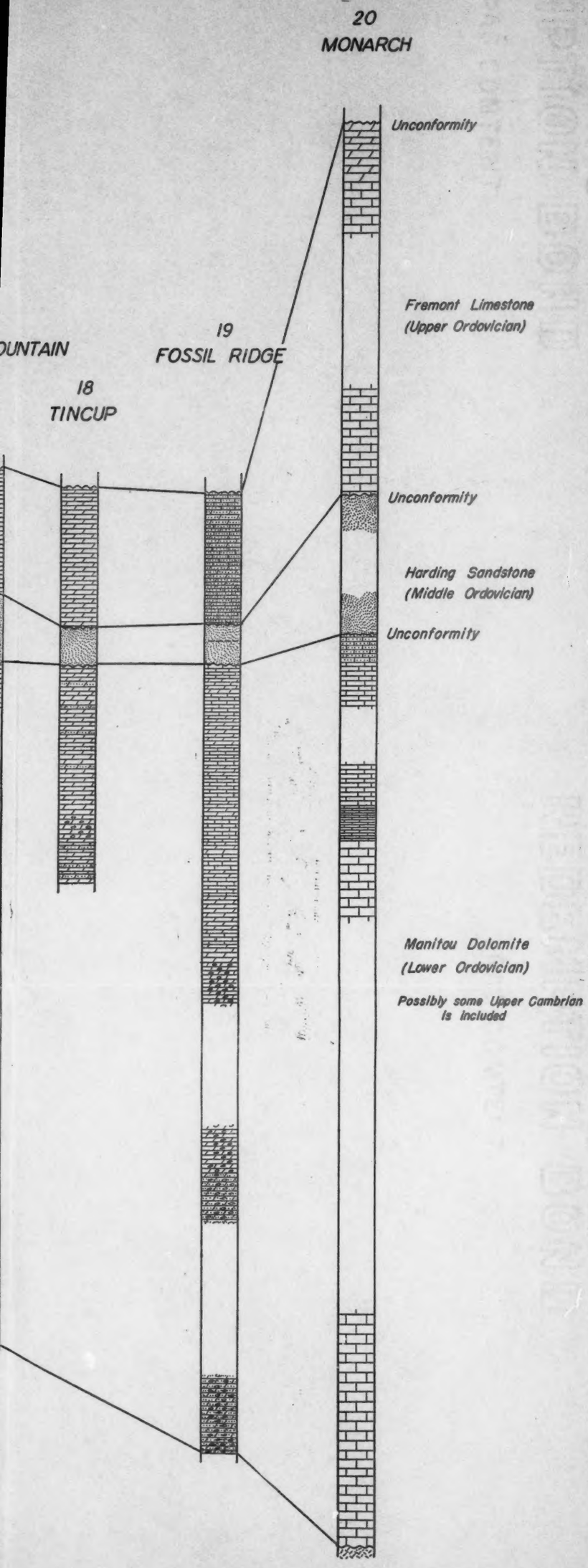


SECTIONS OF ORDOVICIAN FORMATIONS ALONG WEST



SECTIONS OF ORDOVICIAN FORMATIONS ALONG WEST SIDE OF SAWATCH RA


20
MONARCH
Unconformity
Fremont Limestone
(Upper Ordovician)
19
FOSSIL RIDGE
OUNTAIN
18
TINCUP
Unconformity
Harding Sandstone
(Middle Ordovician)
Unconformity
Manitou Dolomite
(Lower Ordovician)
Possibly some Upper Cambrian
is included

CH RANGE

some constituent has been dissolved out. White to light-gray cherts are abundant above the lowest 15 or 20 feet of beds. The cherts occur as round or oval concretions and streaks and as branching cylindrical forms along the bedding planes. The middle unit comprises 60 feet of light-gray dolomites, some of which appear pink or greenish on weathered surfaces. Cherts are much less common than in the beds below, and the beds are from 4 inches to 2½ feet thick. The upper unit, 78 feet thick, includes massive, bedded dolomites, light to dark gray, with a fine-grained and compact texture. Fragments of crinoid stems and silicified shells were noted. Some layers show a fibrous structure on weathering, suggesting algal limestone. These divisions grade into one another and are considered of a rather local development.

Along the southern end of Taylor Park, from Tincup and Round Mountain westward to Cement Creek, the Manitou dolomite develops normally, with basal layers containing sand grains in the dolomite, then 40 to 60 feet of thinly bedded siliceous dolomites containing considerable chert, and then a series of darker, more massively bedded dolomites with little or no chert. (*See* detailed sections given later in paper; also Fig. 4.)

Along the northern slopes of Mount Tilton near the head of the Taylor River, and extending over the divide into the southern end of the Aspen district, a series of beds forms a transition from typical Sawatch quartzite into typical Manitou dolomite, through a zone in which both lithologic types occur with depositional breccias (Fig. 4; Pl. 2), and it is difficult to draw a boundary. In the plotted sections it has been placed at the base of the dolomitic limestones above the highest quartzites. The lower beds are dark gray with breaks of black shale between, which are usually only a fraction of an inch thick, although a few are locally several inches thick. Some lower beds are sandy, and above them is a series of thinly bedded dolomites. Next above is a thick series of more massively bedded dolomites containing cherts which are quite abundant at Mount Tilton in this series and not so abundant in the Taylor Pass and Ashcroft sections.

In the Aspen district the outstanding features of the formation are its great thickness at the southern end of the district and the fact that the lower layers are more sandy than is usual farther south. Some bedding planes show ripple marks. On Richmond Hill some beds are nodular and on weathered surfaces showed indistinct fibrous and concentric structure that suggests algal limestones. Spurr (1898, p. 9-10) has described the beds in this district.

A series of edgewise conglomerates north of the Frying Pan River forms the boundary between the Sawatch and the Manitou beds. They are well developed between the Frying Pan River and Brush Creek. The lower Manitou beds are sandy dolomites, thin-bedded, and with indications of shallow-water deposition such as small ripple marks and sun cracks. Above these lower beds is the usual series of thinly bedded siliceous dolomites that contain chert nodules and stringers. Chert, however, is not so abundant as farther south. Breaks of shale occur between some of the dolomite layers, and many beds are now highly silicified.

From the top of the Sawatch quartzite at Gilman a thick series of transition beds overlain by shales, sandy dolomites, dolomitic sandstones, and sandstones extends

up to the Parting member of the Chaffee. The absence of fossils makes it difficult to say how much of the series belongs to the Manitou, but on the basis of lithology it is very improbable that the thickness of the Manitou is more than 23 feet and it may be as little as 10.

TABLE 6.—*Thicknesses of the Ordovician formations along the Sawatch Range*

Name of section	*Location*	*Manitou dolomite*	*Harding sandstone*	*Fremont limestone*
Garfield	(sec. 29, T. 50 N., R. 6 E.)	244.5	37.5	100
Fossil Ridge	(sec. 11-12, T. 51 N., R. 3 E.)	212	10.2	37
El Capitan mine	(sec. 19, T. 15 S., R. 81 W.)		11	38
Cross Mountain	(sec. 20, T. 15 S., R. 82 W.)	200.2	10	32
Round Mountain	(sec. 28, T. 14 S., R. 81 W.)	99.0	7	28
Deadman Creek	(sec. 14, T. 14 S., R. 84 W.)	218	0	65
Cement Creek 1	(sec. 18, T. 14 S., R. 84 W.)	182.5	0	40.4
Cement Creek 2	(sec. 14, T. 14 S., R. 85 W.)	178.0	12.1	38.0
Mount Tilton	(sec. 22–27, T. 12 S., R. 84 W.)	273	0	6
Taylor Pass	(sec. 9?, T. 12 S., R. 84 W.)	260	0	0
Ashcroft	(sec. 22–29, T. 11 S., R. 84 W.)	370	0	0
Richmond Hill*	(sec. 31?, T. 11 S., R. 84 W.)	375	0	0
Tourtelette Park*	(sec. 19?, T. 10 S., R. 84 W.)	300–325	0	0
Aspen Mountain*	(sec. 18?, T. 10 S., R. 84 W.)	225–250	0	0
Smuggler Mtn.*	(sec. 10?, T. 10 S., R. 84 W.)	130–200	0	0
Frying Pan River	(sec. 19, T. 8 S., R. 83 W.)	117.4	0	0
Woods Lake	(sec. 19, T. 7 S., R. 82 W.)	130.5	0	0
Brush Creek	(sec. 19, T. 7 S., R. 83 W.)	62.4	0	0
East Lake Creek	(sec. 19, T. 5 S., R. 82 W.)	39.4	0	0
Gilman	(sec. 19, T. 6 S., R. 80 W.)	20	0	0

* The thicknesses at Richmond Hill, Tourtelette Park, Aspen Mountain, and Smuggler Mountain, all in the Aspen district, were obtained from Mr. J. P. Rolfing of Aspen who has extensive records of the thicknesses in most of the mine workings. The writer, however, visited the localities with Mr. Rolfing.

THICKNESS: The Manitou dolomite ranges greatly in thickness even in short distances. In the Monarch and Tomichi districts Crawford (1913, p. 57–58) found that the lower limestone member of his Tomichi limestone (Manitou dolomite of this report) ranges in thickness from 75 to 290 feet and noted a gradual thinning to the south and southwest of Monarch. Table 6 shows the thickness observed during the present work.

These differences in thickness of the Manitou dolomite are partly a result of original differences in deposition and partly a result of post-Manitou erosion. Inasmuch as in places it is unconformable on the Sawatch quartzite or even on the pre-Cambrian rocks (Monarch district), whereas at other localities as between Mount Tilton and Ashcroft a thick transitional series lies between the typical Sawatch and Manitou beds, differences in thickness are attributed in part to the original deposition. The transitional series makes the drawing of a boundary difficult, and quite possibly the writer has not always drawn it at exactly the same horizon. This may alter the amounts shown in the table.

Unquestionably, post-Manitou erosion was responsible for the greatest observed changes in thickness. This could have occurred during three different times: (1) between the deposition of the Manitou and the Harding sediments, (2) following the deposition of the Harding beds and before the Fremont limestones were laid down, and (3) in the long period from the late Ordovician until after the middle of the Devonian period. Some time after the deposition of the Fremont limestone and the withdrawal of the sea the crustal tilting in the Sawatch Range province raised the northern end, and in this interval, before the deposition of the Chaffee, erosion removed much of the material previously deposited in the northern end of the area. A study of the charts, especially Figure 4 and Plate 2, will clarify the effects of these erosion intervals.

CONDITION OF DEPOSITION: The deposits in the Manitou dolomite were laid down in shallow sea water. Lands adjoining the sea were low and of slight relief. The beds in the lower and middle portions contain edgewise conglomerates, show fine ripple marks, and carry abundant cherts, all of which are taken to indicate deposition in very shallow water. The sun-cracked bedding planes at a few localities point to shoreline conditions. The character of the sediments—sandy dolomites, dolomites, and siliceous dolomites—indicates deposits in quite shallow water. In the thicker sections the fact that the upper beds are more massive and contain much less chert indicates deposition in somewhat deeper though still relatively shallow waters, farther from the coast line. The fact that ripple-marked surfaces are fewer and that the ripple marks are much coarser in the upper beds corroborates this interpretation.

The question of the origin of chert and dolomite is important in considering the conditions of deposition of the Manitou dolomite as well as of the Devonian and Mississippian sediments. Field evidence indicates that both the dolomites and their included cherts represent primary deposits in shallow sea water, a result of slow deposition of materials brought largely in solution from near-by lands where relief was slight and thorough chemical weathering prevailed.

AGE AND CORRELATION: In the Monarch district Crawford (1913, p. 60) obtained on Monarch Hill *Helicotoma* sp? and indeterminable cephalopods about 50 feet above the base of the Manitou (lower limestone member of Tomichi of Crawford's nomenclature). About 10 feet higher poorly preserved specimens of a "*Dalmanella*" were found. Highly silicified specimens of a specifically undetermined *Orthoceras* were obtained from horizons ranging from the top of the formation down to about 80 feet above the base.

Worcester (Crawford and Worcester, 1916, p. 56) reported fossils from the lower part of his Yule limestone (Manitou of present usage) in the Gold Brick district under the following names: *Dalmanella* cf. *D. testudinaria* (Dalman)?, *D. hamburgensis* Walcott, *Lingula* sp.

The writer obtained a few fossils from the upper Manitou along Fossil Ridge above Boulder Lake (bed 7, Fossil Ridge section) which were identified by Edwin Kirk of the Geological Survey as cystoid plates and columnals and *Manorthis hamburgensis* (Walcott). Cross sections of small, low spiral gastropods and fragments of a brachipod suggesting a *Dalmanella* were observed at the same locality. Some layers in

both the middle and upper Manitou in this vicinity show a fibrous structure on weathering that suggests algal growths.

Along Cement Creek some well-preserved brachiopods were found in float that apparently came from the Manitou. Kirk identified these as *Lingulella sp.*

A number of fossils have been reported from the Manitou limestone of the Mosquito Range (Johnson, 1934, p. 21–22) east of the Sawatch Range.

Paleontological evidence indicates that the formation is early Ordovician and is to be correlated approximately with the Beekmantown of the New York State section.

Harding sandstone.—This is one of the most interesting formations studied in the area even though the sections are thin and the outcrops small. It throws light on an otherwise unknown chapter in the history of the region and indicates a surprisingly widespread distribution of primitive fishes.

NOMENCLATURE AND DISTRIBUTION: The Harding sandstone was named and described by Walcott (1892, p. 153) from outcrops near Canon City, Colorado. Eldridge (1894, p. 6) found beds in the Crested Butte quadrangle containing fish plates, which he recognized as equivalent to those at Canon City but which he included in his Yule formation. Crawford (1913, p. 57–59) included beds in his Tomichi limestone of the Monarch and Tomichi districts that later work has shown to be correlated with the Harding (Kirk, 1930, p. 458). In the Gold Brick district, Worcester (Crawford and Worcester, 1916, p. 53–56) found similar beds, which were included in the lower member of his Yule formation. The writer visited all these and a number of other localities and recognized and delimited the Harding sandstone in many sections studied. The formation crops out only along the southern end of the Sawatch Range from Monarch to the Tincup district and westward across the southern end of Taylor Park to Cement Creek. The outcrops are small and in many places suggest irregular remnants rather than continuous beds.

LITHOLOGIC CHARACTER AND GENERAL RELATIONS: In the region considered in this report, the Harding consists essentially of sandstones, which may be rather calcareous. Streaks of shale or sandy shale are present at some localities. In many places the upper bed or beds have been altered to quartzite. They vary from white to black; in most places they are gray, brown, or purplish black, but the shales and calcareous beds may be white, green, or light greenish gray. As originally deposited, the beds were light colored, and the dark colors and the induration of the upper beds have resulted from post-Harding weathering.

Most characteristic of the formation in the Sawatch Range are the fragments of small fish plates such as are common at the type locality and have been described by Walcott (1892, p. 153), Behre and Johnson (1933), and Bryant (1936). They were present at all localities where the formation was studied and in many places are very abundant. Some weather to show a phosphatic bloom. Others have been replaced by iron oxide and weather to a limonite or hematite stain. They are preserved much the same as the fish plates in the overlying Devonian, except that most of the Harding material has been more thoroughly replaced and indurated. However, the fish plates of the Harding can be readily distinguished from those of the Devonian by their smaller size, thinness, and the ornament. The Ordovician plates are ornamented by perforations and incised patterns, the Devonian material is much larger and thicker, and the ornament is a raised pattern.

FIGURE

FIGURE 1. CONTACT SAWATCH QUARTZITE AND PRE-CAMBRIAN GRANITE
Near Taylor Pass, showing gradation between weathered granite and bedded quartzite.

FIGURE 2. UNCONFORMABLE CONTACT NEAR REDCLIFFE BETWEEN SAWATCH QUARTZITE AND PRE-CAMBRIAN ROCKS

CAMBRIAN—PRE-CAMBRIAN CONTACT

FIGURE 1. EDGEWISE CONGLOMERATE IN PEERLESS MEMBER, SAWATCH QUARTZITE
Along Frying Pan River near Thomasville.

FIGURE 2. UPPER CAMBRIAN SHALY LIMESTONE WITH GRAPTOLITES
(Scale shows centimeters.)

CAMBRIAN SAWATCH FORMATION

The Harding rests unconformably on the Manitou dolomite and at most places is unconformably overlain by the Fremont limestone (Pl. 7, fig. 2). In one locality Devonian beds appear to rest immediately above.

THICKNESS: At Monarch the Harding is represented by quartzites that locally are called "the parting quartzite" by the miners and prospectors. The name "parting quartzite" applied locally to the quartzite facies of the Ordovician Harding sandstone at Monarch should not be confused with the Devonian Parting member of the Chaffee formation, which also crops out in this area. These quartzites are on both sides of the divide and form the best horizon marker in the Paleozoic section. Crawford (1913, p. 57–59) described the quartzites and found them 37.5 feet thick east of Garfield.

In the Gold Brick district, Worcester and Crawford (1916, p. 54–55) observed a quartzite that the present work has shown to belong to the Harding. Good outcrops occur along Fossil Ridge, where 10 feet of quartzite was observed. These quartzites are light-colored, but the upper portion of the formation showed signs of pre-Fremont weathering and were stained a dark reddish brown.

A good exposure of the Harding showing 11 feet of quartzite was observed in an old road cut near the El Capitan mine southwest of Tincup. The lower beds are nearly white, but the upper layers have been stained purplish black. Fish plates are abundant in all the layers.

On Round Table Mountain, northeast of Tincup, the Harding is represented by 7 feet of quartzite. It contains coarse grains and small pebbles of bluish-white quartz.

At Cross Mountain, southwest of Tincup, the Harding is represented by 8 or 9 feet of red-brown, cross-bedded sandstone.

On the west side of Cement Creek about 14 feet of the Harding sandstone is present where the Cement Creek No. 2 section was measured. It is absent, however, a few miles to the northeast on the west side of Cement Mountain and along Deadman's Creek east of Cement Mountain. At the last locality Fremont limestone rests upon a slightly wavy and highly weathered layer of the Manitou dolomite. Where observed on Cement Creek the formation consists of quartzites and sandstones overlain by calcareous sandstones. No outcrops of the formation were observed north of this locality.

As already noted, the observed thicknesses range from a few feet to a maximum of about 38 feet near Monarch Pass (Table 6). The formation is missing north of T. 13 S., at the south end of Taylor Park. Originally it probably extended over a much larger area, as in the known localities definite evidence may be observed of considerable erosion after the deposition of the Harding, and along the Mosquito Range outcrops are found as far north as T. 11 S.

CONDITIONS OF DEPOSITION: The coarse sand grains, the cross-bedding, the ripple marks on some surfaces, and the abundant worm borings and casts of fucoids in the Harding suggest deposition in shallow water. So little is known of its extent, particularly beneath the later formations west and south of the Sawatch Range, and so much of it has obviously been removed by post-Harding erosion (both pre-Fremont and pre-Chaffee) that it is difficult to visualize its original distribution. The Harding is absent north of Taylor Park and thin around the park, but it gradually thickens

southward toward Monarch and continues to thicken to the south and east of Monarch. Burbank (1932, p. 9) reports from 60 to 90 feet of beds correlated with the Harding sandstone in the Bonanza district, whereas from 80 to 150 feet exists in the Canon City region (Brainerd, Baldwin, and Keyte, 1933, p. 382–384). It thins to the northwest, as Vanderwilt (1935a) and Fuller found only 5 feet of the sandstone along Yule Creek and could not recognize any along the Colorado River above Glenwood Springs.

This distribution may mean deposition in a narrow trough, with a more or less east-west trend, and derivation of most of the sediments from land areas south, southwest, and north of the present southern Sawatch Range, or the distribution could have resulted from post-Harding uplift along and north of the northern half of the present Sawatch Range, followed by more erosion in that direction. The wedging out of the Fremont limestone to the northwest without change in lithologic character, the rapid thinning of the Manitou dolomite north of Aspen, and the northward changes in lithologic composition of the Lower Devonian suggest tilting and erosion as the more probable causes.

An exhaustive study of the fish plates recently completed by Bryant (1936) throws light on the character of the animals and gives clues to their habits and to the environmental conditions under which the Harding sediments were deposited.

AGE AND CORRELATION: In the area studied no fossils except the fish plates mentioned were found in the formation. These, however, are identical with specimens obtained from the type locality at Canon City where they are associated with a large invertebrate fauna which Kirk (1930) designates as about late Black River or early Trenton age (Middle Ordovician).

Fremont limestone.—This limestone makes a good horizon marker wherever present.

NOMENCLATURE AND DISTRIBUTION: The Fremont limestone as differentiated in the present work includes beds previously called by many names. Eldridge (1894, p. 6) included remnants in the middle division of his Yule formation. It forms the upper part of the Tomichi limestone of Crawford (1913, p. 56–61) in the Monarch and Tomichi districts and division three of the lower fossiliferous member of Crawford and Worcester (1916) Yule limestone of the Gold Brick district. Burbank (1932, p. 9–11) included it in the Tomichi limestone of the Bonanza district. Kirk (1930, p. 457–459) obtained sufficient paleontologic evidence to establish the presence of beds carrying a typical Fremont fauna along the south end of the Sawatch Range. The present work shows that the formation can readily be differentiated on lithologic and paleontologic evidence.

The Fremont limestone was present in all the sections studied along the west side of the Sawatch Range from Monarch to Texas Creek, on Fossil Ridge, and along the west side of Taylor Park almost to the head of the Taylor River near the Gunnison-Pitkin County boundary (Pl. 2). At the northern localities it has been reduced to thin, isolated remnants and is absent north of Taylor Park. As originally deposited it probably extended much farther but was removed by erosion before the deposition of the Chaffee in late Devonian time.

LITHOLOGIC CHARACTER AND THICKNESS: The Fremont limestone consists of a light-gray to gray-brown dolomite or dolomitic limestone which weathers dark gray

or nearly black. At a few localities some layers appear to be nearly pure limestone, but most of the formation is highly dolomitized. Some basal beds are slightly sandy. The bedding is massive, and weathering tends to produce a rough, jagged surface. Most weathered surfaces show numerous fragments of crinoid stems or corals, and colonies of chain corals are common. The formation is a pronounced cliff maker in many places. The upper layer or layers show signs of weathering and recrystallization before the deposition of the overlying Devonian.

The formation lies unconformably on the Harding sandstone or older formations (Pl. 7, fig. 2) and is separated from the overlying Devonian sediments by an unconformity.

In the Monarch district the Fremont consists of about 100 feet of dark-gray dolomitic limestone. In the Gold Brick district Crawford and Worcester (1916, p. 55) found it of variable thickness—65 feet on Fairview Mountain, 47 feet near Pitkin, and only 35 feet on Fossil Ridge. During the present work thicknesses of 34 to 38 feet were measured along Fossil Ridge. Near the El Capitan mine, southwest to Tincup, the Fremont is represented by about 37 feet of dark-gray dolomite. On Round Mountain, northeast of Tincup, 28 feet of dark-gray, massively bedded dolomitic limestone belongs to the Fremont. On Cross Mountain, about 6 miles west-southwest of Tincup, the formation is 32 feet thick. Along Cement Creek the 38 to 40 feet of the Fremont limestone consists of typical gray, massively bedded dolomitic limestone. At one locality the lowest layer is a depositional breccia of limestone fragments in a sandy matrix. On Deadman's Creek, the Fremont limestone is 65 feet thick. Coarse ripple marks, 7 to 10 inches wide, were observed on bedding planes near the base of the formation. Near the head of the Taylor River, on the north slope of Mount Tilton, small wedgelike remnants of the Fremont limestone occur between the Manitou dolomite and the overlying Devonian sediments. The Fremont was absent north of the Taylor River.

Thicknesses of the various sections measured are tabulated (Table 6). Changes are considerable, even within short distances. However, in general, from a maximum of about 100 feet near Monarch the formation thins northward and wedges out near the head of the Taylor River (Pl. 2). It thickens to the east and southeast of Monarch; Burbank (1932, p. 10) reported about 300 feet of beds correlated with Fremont limestone along Kerber Creek, and Walcott (1892, p. 153) and Brainerd (1933, p. 385) have described a thick section at the type locality near Canon City. West of the Sawatch Range, Vanderwilt (1935a) and Fuller report 63 feet of Fremont limestone along Yule Creek and 60 feet on Treasure Mountain. The differences in thickness along the Sawatch Range probably have resulted more from erosion during Silurian and Devonian times than from differences in original deposition. This is indicated by the rapid and sometimes erratic changes in thickness of outcrops close together and by the fact that practically no lithologic change in the formation was observed as it thins to the north. Everywhere it is a fossiliferous dolomitic limestone without evidence of a clastic near-shore phase.

CONDITIONS OF DEPOSITION: The Fremont limestone represents material laid down in sea water of moderate depth, which received very little sand or mud from the adjoining land. The abundance of corals, crinoids, and other forms, together with

the absence of sandstones and shales, indicates clear, silt-free waters. Only the basal beds are sandy or conglomeratic, and ripple marks were observed only in the basal beds and only at one locality. Apparently the sea rapidly encroached on an area of slight relief and rapidly pushed the shore line beyond the area of the present Sawatch Range. The adjoining lands were probably of slight relief and were covered with calcareous rocks.

So much of the original Fremont limestone has been removed by erosion and so little is known of its present extent west of the Sawatch Range that reconstruction of the distribution of land and sea in the central Colorado area during Fremont time is impossible.

AGE AND CORRELATION: Corals and crinoid stems are abundant, but brachiopods are scarce. The writer recognized the following forms:

Halysites catenulatus
H. sp., possibly *H. gracilis*
Streptelasma sp.
Receptaculites sp.
Dinorthis cf. *D. subquadrata*
Rhynchotrema sp.

Crawford (1913, p. 60) reported *Receptaculites oweni*, *Halysites catenulatus*, and small cup corals from the lower 50 feet of the formation, upper limestone member of Tomichi limestone of Crawford, and cup corals in the higher beds. Crawford and Worcester (1916, p. 56) obtained fossils from the Fremont limestone of the Gold Brick district (lower member of Yule limestone, according to his nomenclature) which Junius Henderson, of the University of Colorado, identified as follows:

Halysites catenulatus
Receptaculites oweni
Platystrophia sp.
Heliolites sp. (probably a Calapoecia)
Undetermined corals, brachiopods, gastropods, and fish scales.

Kirk found corals near Monarch and dated the formation as Ordovician, probably pre-Richmond, but post-Trenton, approximately equivalent to the Montoya of Texas and New Mexico and part of the Bighorn of Wyoming. Although the lower part of the Fremont limestone at Canon City, Colorado, contains a fauna of Black River age, no Middle Ordovician fauna has been found in the Fremont of the Sawatch Range.

DEVONIAN SYSTEM

Chaffee formation.—Devonian deposits are present in all sections studied. A number of terms have been applied to these Devonian strata in the past. Eldridge (1894, p. 6) included the lower part of the Devonian in his Yule formation, of supposed Ordovician age, and the upper part of the Devonian with the Mississippian in his Leadville limestone. Spurr (1898, p. 13–28) recognized the lower beds as Devonian and used the term Parting for them but included the upper beds with the Mississippian under the name Leadville limestone. Crawford (1913, p. 61–66) included the Devonian and Mississippian under the term Ouray limestone. Worcester and Crawford (1916, p. 53–61) called the lower sandy and shaly portion of Devonian the Fairview shale and included it with the Ordovician as the upper member of his Yule limestone, and the upper dolomitic beds with the Mississippian in his Leadville limestone. Kirk (1931) visited some of the localities and applied the name Chaffee formation to all the Devonian deposits in Colorado east and north of the San

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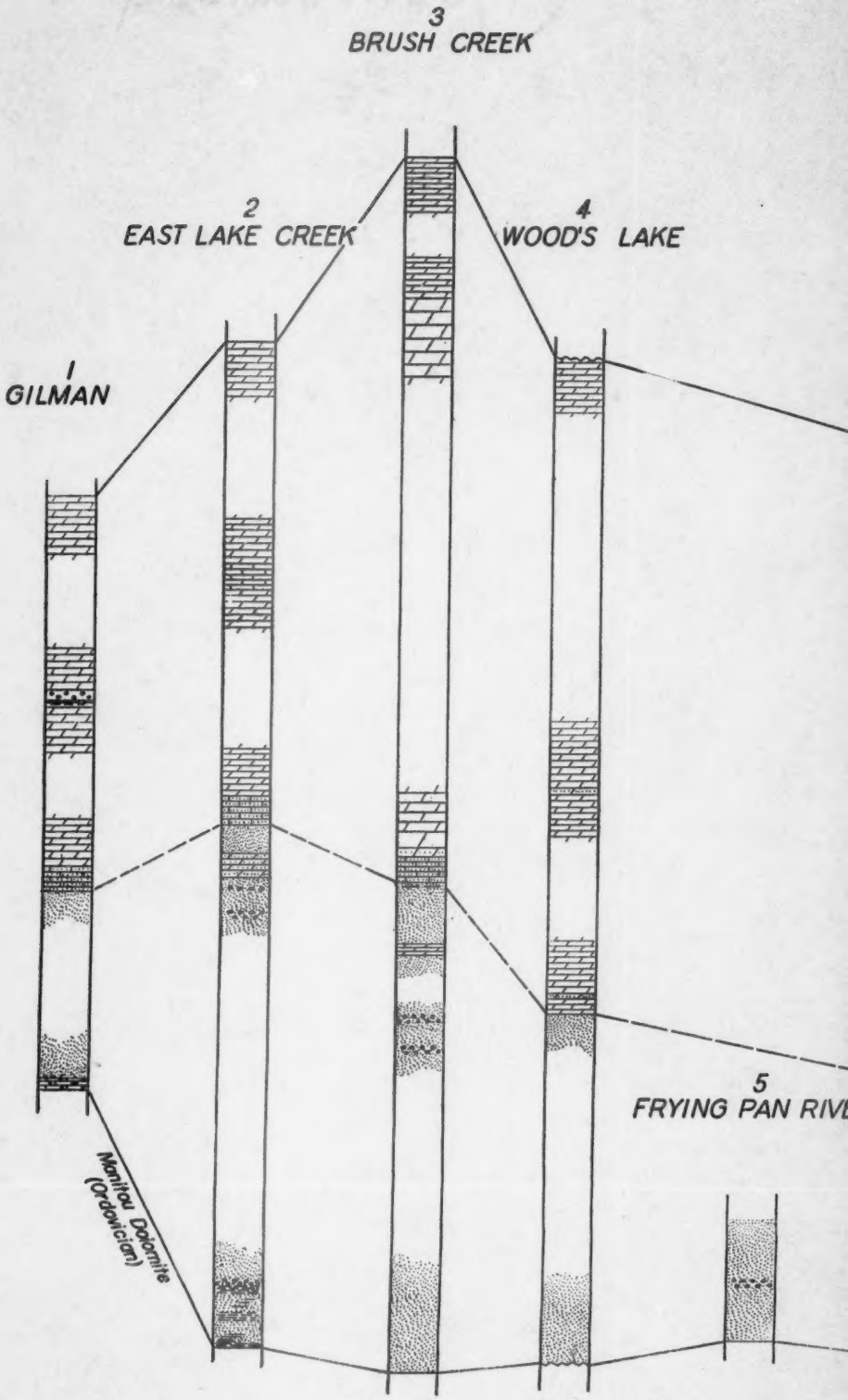
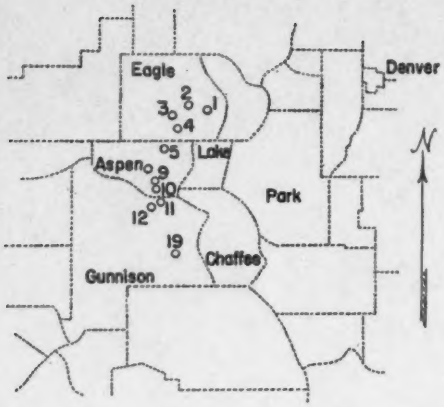


SECTIONS OF DEVONIA



AKE

9
ASHCROFT

11
MOUNT TI

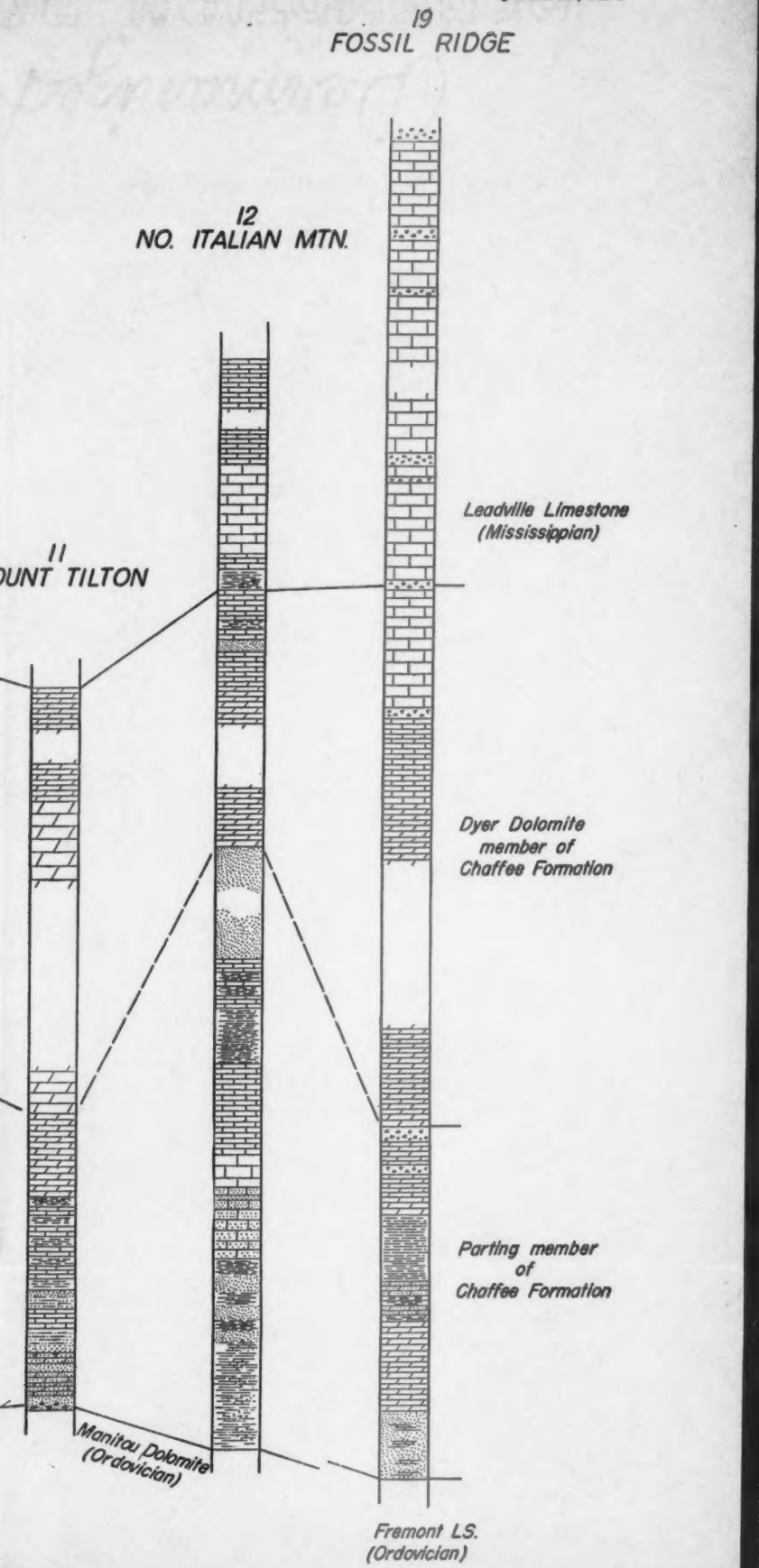
10
TAYLOR PASS

ASPEN

5
FRYING PAN RIVER

10
feet
0
Scale

ECTIONS OF DEVONIAN ROCKS ALONG WEST SIDE OF SAWATCH RANGE


19
FOSSIL RIDGE
12
NO. ITALIAN MTN.
11
OUNT TILTON
Leadville Limestone
(Mississippian)
Dyer Dolomite
member of
Chaffee Formation
Parting member
of
Chaffee Formation
Manitau Dolomite
(Ordovician)
Fremont LS.
(Ordovician)

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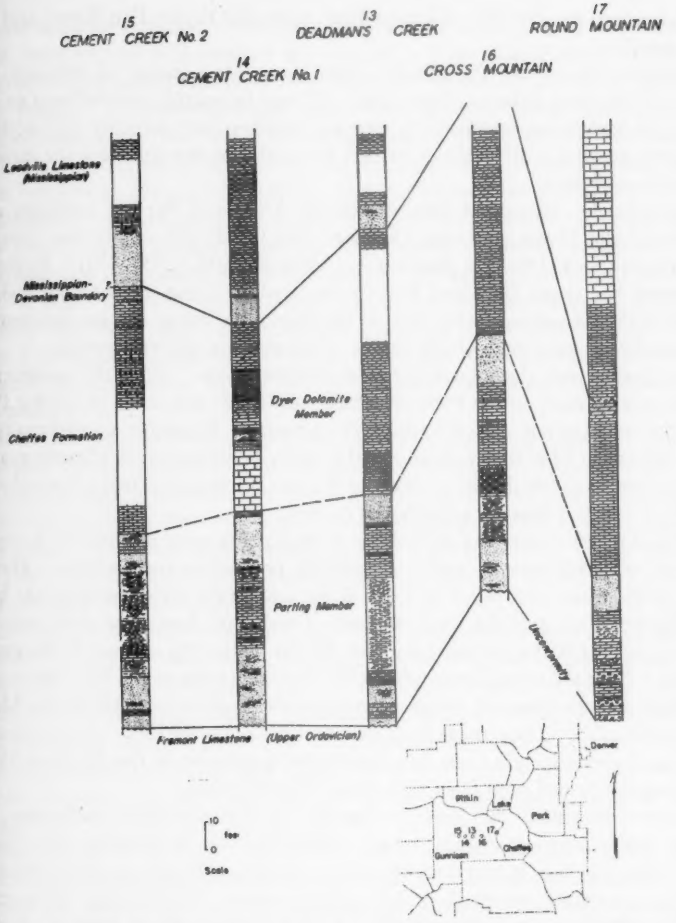


FIGURE 5.—*Sections of Devonian rocks across the south end of Taylor Park*

Juan Mountains. In the present paper the term Chaffee is used for all the Devonian sedimentary rocks.

DISTRIBUTION: Devonian beds crop out along the west side of the Sawatch Range between Monarch Pass and the head of Texas Creek, and from the northern end of Taylor Park to the vicinity of Tennessee Pass. Another series of outcrops extends along the southern end of Taylor Park to Cement Creek, then along the western side of Taylor Park (Fig. 5; Pl. 5).

Good outcrops were found on Fossil Ridge (Pl. 8, fig. 2), along Cement Creek, near Wood's Lake, and on the cliffs at Gilman. In many places a part of the section is covered. Some of the outcrops are discontinuous as a result of faulting (Fig. 5;

Pl. 5), as along the east side of Taylor Park, along the Frying Pan River, and north of Monarch.

GENERAL RELATIONS: The Chaffee shows the greatest variety of lithologic types of any of the lower Paleozoic formations. It may be roughly divided into an upper and a lower member, which grade into one another both laterally and vertically. Both were present at all localities studied, but each may not represent the same time interval everywhere.

The members correspond generally to the Dyer and Parting members of the Chaffee of the Mosquito Range (Johnson, 1934, p. 23–25) and to the Ouray and Elbert formations of the San Juan region (Burbank, 1930, p. 157–159). In the present report the terms Dyer and Parting are used for these members as their continuity with the corresponding beds of the Mosquito Range can be demonstrated, whereas their connection with the San Juan deposits has not been proved.

The Chaffee rests unconformably on older formations. Along the southern part of the range it rests on the Fremont limestones (Pl. 5) and north of Taylor Park it rests on the Manitou. At the top of the formation is another unconformity. In most places the Chaffee is overlain by the Leadville limestone of Mississippian age, but at a few localities the Pennsylvanian Weber (?) formation comes down almost to the Devonian, if it does not actually rest upon it.

At most places where the basal contact of the Chaffee could be observed it appeared to be a relatively smooth surface essentially parallelling the bedding. However, some irregularities were noted on Fossil Ridge and on the divide between the head of the Taylor River and the head of Castle Creek that forms the Gunnison-Pitkin County line. On the northern slope of Mount Tilton the contact is distinctly irregular. Near the top of the mountain the Devonian rests on the Manitou dolomite, but farther down irregular elongate masses of Fremont occur between the Manitou and the Chaffee. These range from thin wedges to 9 to 10 feet. At one place near the top of the mountain there is a steep-sided depression in the Manitou 15 or 18 feet deep which had been filled with Devonian sediments.

PARTING MEMBER: The lower or Parting member consists of sandstone, shale, sandy shale, calcareous shale, clayey limestone, thin limestones, and dolomitic limestones (Pl. 8). It may be gray, green, yellow, or brown, in most places light. The outcrops often weather to a light yellow brown. The lithology varies greatly, even in short distances. The individual beds are at many places lenticular and interfinger, grading laterally from one to another.

At the northern end of the range the lower member consists mainly of sand, with some shale and very few calcareous beds, and has the typical lithology of the Parting quartzite member in the Mosquito Range (Johnson, 1934, p. 23–24). Thus, at Gilman it consists of nearly 40 feet of coarse, gritty quartzite, almost white, with about 2 feet of coarse conglomerate below and some underlying shales and sandy shale.

Southward the percentage of sandstone and coarse clastic material decreases, and the member grades into shale, in part sandy. South of the Roaring Fork River the member consists largely of shale, argillaceous limestone with thin sandstone, and shaly sandstone (Pl. 8). The sandstones are cross-bedded in many places. South of Aspen they are commonly ripple-marked, and some even show sun cracks. Near

the base was a thin bed or zone of fine-grained to shaly sandstone in which the bedding planes were covered with casts of salt crystals. These were observed at the same horizon in every section measured from Ashcroft to Fossil Ridge and in the Cement Creek region. Well-developed sun cracks were found at the same horizon on the prong of Fossil Ridge that forms the divide between Boulder and Comanche creeks. Sediments that appear to be sun-cracked were also seen at the same and slightly higher horizons at some other localities. In most places there is a basal sandstone or conglomerate. On the northeast side of Fossil Ridge the basal conglomerate contains among other materials definite fragments of Fremont limestone. Other sandstones may occur anywhere in the member, although they are largely confined to the lower part. However, rather massive sandstones occur at the top of the member at several localities. The sandstones commonly show cross-bedding and are white to cream, weathering to yellow to dark brown. Some are slightly arkosic and contain a few small frayed flakes of mica. In many places the sandstones are impure, dolomitic or argillaceous.

Above the basal sandstone are numerous calcareous mudstones or argillaceous limestones which in places are in beds as much as 6 feet thick. They are fine-grained, show well-developed conchoidal fracture, and lithologically are the most characteristic beds of the member. The lower argillaceous beds grade upward into gray limestone and dolomitic limestone with progressively fewer alternations of clastic sediments until finally the deposits consist almost entirely of dolomitic limestone, forming the upper or Dyer dolomite member.[1]

Lithologically, the lower member of the Chaffee along the northern end of the range resembles the Parting quartzite of the Leadville district, but in the Cement Creek region and along the southern end of the Sawatch Range it resembles the Elbert formation of the San Juan region. Between the Frying Pan River and the southern end of the Aspen district the lithology is transitional between the two.

The thickness of the sandstones, shales, mudstones, impure limestones, and dolomites in the lower member is different in every section measured (Table 2) ranging from about 40 to 100 feet and averaging 60 feet.

Dyer Dolomite Member: The Dyer member consists mainly of dolomite and dolomitic limestones; with some beds or lenses of nondolomitic limestone. The dolomites are commonly sandy, clayey, or shaly. Streaks, thin beds, and lenses of sandstone or shale occur between the dolomites. Near the base of the member light-gray and greenish cherts occur as irregular rounded nodules and as branching cylindrical forms along the bedding planes. Higher up are rounded nodules of dark-gray chert in the more massive dolomites. The bedding is thin to medium, in most places thinner than in the overlying Leadville limestone. The deposits as a whole are light to dark gray but commonly weather to brown or yellowish.

Although the characteristic features can easily be generalized the detail varies greatly from one locality to another and commonly even within short distances, as shown in Figure 5 and Plate 5 and in the detailed sections at the end of the paper.

The thickness in the various sections studied ranges widely. The minimum observed was about 70 feet, and the maximum about 200 feet. The greatest thicknesses

[1]For details of lithologic constitution in the various localities, the reader is referred to the sections at the end of this paper.

were in the Aspen mining district and between Pitkin and Fossil Ridge. To the east along the Mosquito Range the Dyer dolomite member is much thinner (averaging about 70 feet) (Johnson, 1934, p. 18), but it thins gradually westward toward Yule Creek (Vanderwilt, 1937, p. 12, 17). Part of this apparent great range in thickness may result from incorrect choice of the Devonian-Mississippian boundary, which was not defined in several sections. In some localities it results from irregularities of deposition, the earlier sandy type of deposition having persisted in some places while the dolomites were being deposited elsewhere. Much of the difference, however, is very probably the result of erosion between the end of Chaffee deposition and the beginning of the deposition of the Mississippian Leadville limestone.

CONDITIONS OF DEPOSITION: Late in Devonian time the seas seem to have gradually advanced and slowly covered the area. In the preceding long interval of erosion the lands had been worn down to a low, nearly flat, surface. The advancing sea reworked the soil and weathered material, forming the basal sandstones and conglomerates. For a time the water was very shallow, and one can visualize numerous estuaries and lagoons along the shores with beaches and bars and streams bringing in sediments that were moved and sorted by waves and along-shore currents. Changes in direction and intensity of the prevailing winds accompanied the storms, and the seasons affected the currents and waves. Under such conditions the variable sediments of the lower member were deposited. The materials in the sandstones—quartz, feldspar, mica flakes, and, rarely, tourmaline—resulted from the erosion of pre-Cambrian rocks. The dolomitic muds and the fragments of dolomite in the sandstones suggest materials derived from the weathering and erosion of the Ordovician dolomitic limestones. The ripple marks indicate shallow water, and the occasional sun cracks and casts of salt crystals indicate exposure to the air between tides or storms, or in dry seasons. During this time a granite landmass appears to have existed north of the present Sawatch Range. Erosion probably provided the abundant sands of the Parting quartzite type of deposits of the northern Mosquito Range and of the northern half of the Sawatch Range. Its general location is suggested by the thickening and coarsening of the sandstones toward the north, with the maximum at the northernmost sections studied. Still farther north, about 9 miles east and 8 miles northeast of Minturn, a thin quartz pebble conglomerate interpreted as Devonian (Lovering and Johnson, 1933, p. 365) overlapped the pre-Cambrian rocks. No Chaffee sediments have been found north of these localities, and the features cited suggest the location of the shore line and a source of the sediment during at least part of Chaffee time.

The seas continued their gradual advance until the shores were pushed considerably beyond the area under consideration, and only fine sediments such as dolomites and impure dolomites were deposited.

The origin of the dolomites in both the Devonian and the Mississippian is important. The writer considers them to represent original deposits of dolomitic muds laid down in moderately shallow to very shallow water, extending close to the old shore lines in some places. The subject is discussed later in connection with the Mississippian sediments.

AGE: Fossils have been obtained from the lower member of the Chaffee at a number of localities. Fragments of bones, plates, and the teeth of fishes were collected.

On Fossil Ridge (secs. 11–14, T. 51 N., R. 3 E.) they were obtained from the basal conglomerate and from beds up to 10 feet above the base (Pl. 8, fig. 2). Along Deadman's Creek (sec. 14, T. 14 S., R. 84 W.) they were found in a slabby sandstone 19 feet above the base. Near Taylor Pass (sec. 9, T. 12 S., R. 84 W.) poorly preserved bone fragments were observed in a sandy layer 55 feet above the base. On Cross Mountain beautifully preserved specimens were obtained from a sandy calcareous depositional breccia 81 feet above the base of the Devonian and immediately underlying the dolomites of the upper member (Pl. 8, fig. 1).

Members of a Colorado Geological Survey party obtained fish fragments from the basal sandstone (Crawford and Worcester, 1916, p. 56–59) in the Gold Brick district, and Spurr (1898, p. 22) reported fish remains from the Parting quartzite at Aspen.

W. L. Bryant of Providence, Rhode Island, studied the fish material collected in connection with the present work and states:

> "Although these remains are fragmentary and often badly eroded one can distinguish among them the spines and pavement teeth of elasmobranchs, fragments of arthrodire plates, the scales and teeth of crossopterygian fishes and the dental plates of dipnoans.
>
> "The most abundant material consists of detached scales, jaw fragments, head bones and teeth of a large crossopterygian fish. . . . Perhaps the nearest American relative of this fish is *Glyptopomus sayerei* Newberry, from the Catskill rocks of Pennsylvania. Examples were found in the basal beds of the Chaffee formation at Fossil Ridge and along Deadman's Creek.
>
> "Among the fish fossils are three small and broken spines, all evidently of the same species and belonging to the genus *Ctenacanthus*. . . . Only one other elasmobranch fossil occurs in the collection. This is the small cochliodont tooth, largely composed of upright tubes of dentine, described as a new species of *Sandalodus* (*S. minor*). Dipnoans are represented in the collection by a few fairly well preserved dental plates. At least two species occur, both of which are new. The age is Upper Devonian."

Bryant (Bryant and Johnson, 1936, p. 656–659) described the following new species from the collections: *Sandalodus minor* Bryant, *Dipterus johnsoni* Bryant, and *Conchodus parvulus* Bryant.

Suggestions of poorly preserved invertebrate fossils were observed in the lower member at several localities. Good marine fossils were observed in limestones near the top of the lower member or in beds at the base of the upper member. Marine fossils are abundant in the black limestones about 100 feet above the base of the Devonian on Fossil Ridge (about sec. 12, T. 51 N., R. 3 E., N. Mex. Mer.). Along Cement Creek similar fossils were obtained about 90 feet above the base in one section (sec. 18, T. 14 S., R. 84 W.) and at about 70 feet and at 85 feet above the base in section 14, T. 14 S., R. 85 W.

Kirk (1931, p. 232) reports a limestone that contains a definite Ouray fauna within 30 feet of the base of the Devonian on Monarch Mountain. Table 7 shows the invertebrate fossils obtained in connection with the present work.

Girty (1900, p. 36) has recorded the following Devonian fossils, collected by Eldridge on Monarch Hill:

Monotrypella sp.
Schizophoria striatula (= *S. striatula* var. *australis* Kindle (Kindle, 1909, p. 25)
Orthothetes chemungensis (Schuchertella *chemungensis* (Conrad) Kindle)
Orthothetes chemungensis var.
Productella semiglobosa (= *P. coloradoensis* Kindle, 1909, p. 17)
P. subalata?
P. subalata var.
Athyris coloradoensis
Spirifer disjunctus var. *animasensis* (= *S. whitneyi* var. *animasensis* (Girty) Kindle)
Camarotoechia contracta?
Straparollus clymeniodes?
Orthoceras sp.

Crawford reported the following species from a zone 85 to 130 feet above the base of the Devonian near the portal of the Eclipse No. 3 tunnel on Monarch Hill.

Schizophoria striatula var. *australis* Kindle
Schuchertella chemungensis (Conrad) Kindle
Athyris coloradoensis Girty
Spirifer whitneyi var. *animasensis* (Girty) Kindle
Camarotoechia endlichi (Meek) Schuchert
C. contracta (Hall)

TABLE 7.—*Invertebrate fossils from the Chaffee formation*

	Locality number						
	1	2	3	4	5	6	7
Monotrypella sp.	X	X	X				
Fenestella sp.	X	X	X				
Schuchertella chemungensis (Conrad)	X	X	X			X	
Spirifer notabilis Kindle							X
S. whitneyi Hall		X				X	
S. animasensis Girty			X	X	X		X
Athyris coloradoensis Girty		X	X	X		X	X
Camarotoechia cf. *C. contracta* (Hall)		X	X				
C. endlichi (Meek)		X	X	X			X
Schizophoria striatula var. *australis* Kindle						X	
Productella coloradoensis Kindle		X					
Diaphorostoma sp.					X		

Locality 1. Bed 39, Cement Creek Section 2.
2. Bed 36, Cement Creek Section 1, sec. 18, T. 14 S., R. 84 W.
3. Bed 24, Fossil Ridge section, T. 51 N., R. 3 E.
4. Bed 24, Fossil Ridge section, about 1 mile N.E. of No. 3.
5. Bed 46, Deadman Canyon section, sec. 14, T. 14. S., R. 84 W.
6. Bed 24, Fossil Ridge section, about 1 mile w. of No. 3.
7. Bed 25, Glenwood section, Canyon of Colorado River, about ½ mile above Glenwood Springs.

Crawford and Worcester (1916, p. 62) reported the following from the lower part of the Devonian limestone of the Gold Brick district:

Streptelasma or *Zaphrentis*
Crania ? sp.
Schuchertella chemungensis (Conrad)
Camarotoechia endlichi (Meek)
Athyris coloradoensis Girty
Spirifer whitneyi Hall
Euomphalus cf. *E. eurekensis* Walcott
Undetermined Polyzoa and fish remains

CORRELATION: The fossils indicate an Upper Devonian age for all the Chaffee.

The lower member of the Chaffee in the Sawatch Range is correlated with the Parting member of the Mosquito Range and the Elbert of the San Juan region. A lateral gradation extends from the Parting type of lithology at the north end of the range to the Elbert type at the southern end. (*See* sections and Plate 5.) The upper member in the Sawatch Range is correlated with the Dyer dolomite member of the Mosquito Range and the Ouray limestone of the San Juan region. The correlation between members is only approximate, and the members themselves do not everywhere include beds of exactly the same time equivalence, as unquestionably some deposits of the Elbert and Parting type were being formed at some places after the deposition of beds of the Ouray and Dyer type had begun elsewhere.

DEVONIAN-MISSISSIPPIAN BOUNDARY: The boundary between the Devonian and Mississippian in central Colorado has been a problem ever since the discovery of

Devonian strata beneath the Carboniferous. The problem is made difficult by similarity in lithology between the upper beds of the Devonian and those of the Mississippian and by the scarcity or absence of fossils in these lithologically similar beds. Recently progress has been made toward a solution. In the Mosquito Range a sandy zone has been recognized at the base of the Mississippian (Behre, 1929, p. 38) that contains or is overlain by depositional breccia of limestone fragments in a sandy or calcareous matrix (Johnson, 1934, p. 25). Gibson (Crawford and Gibson, 1925, p. 38) recognized the same bed in the Red Cliff district. The writer found it in every section studied from Gilman to the Aspen district, and Vanderwilt has described it for the Aspen district, where the sandstone is thin (5 inches to 2 feet), overlain by about 6 feet of sandy dolomites, which commonly contain streaks of depositional breccia. Above these is 15 or 20 feet of dolomite, which contains abundant nodules and stringers of dark-gray to black chert. Commonly this cherty dolomite is more conspicuous underground than the sandy zone.

The same zone was identified southwest of the Express Mine several miles south of Ashcroft as a 2-foot bed of sandstone, overlain by sandy depositional breccia, which in turn is overlain by dolomites containing abundant dark chert. It was again recognized on the northern slope of Mount Tilton near the head of the Taylor River, where the sandstone is somewhat thicker but is again overlain by sandy depositional breccia and chert-bearing dolomites. In the sections farther south the boundary is uncertain, not from lack of a sandstone overlain by depositional breccia, but because there are several, separated by considerable intervals of dolomite and limestone from which no fossils have been obtained. On the stratigraphic sections (Fig. 5; Pl. 5) the boundary is shown by a broken line south of Mount Tilton; it has been drawn above rocks carrying Devonian fossils at the lowermost sandstone that is overlain by breccia. This may not be the true boundary, as in several places—*e.g.*, Fossil Ridge and Cross Mountain—other sandstones overlain by or containing depositional breccia occur beneath beds that contain definite Devonian fossils. Therefore the Devonian boundary may possibly extend higher than shown, particularly on Fossil Ridge, Cross Mountain, and along Cement Creek. A detailed study of the Devonian and Mississippian in those areas will be necessary for complete solution of the problem.

MISSISSIPPIAN SERIES, CARBONIFEROUS SYSTEM

Leadville limestone.—Mississippian beds occur in all sections studied and are of especial interest as they contain most of the ore deposits of the Aspen, Pitkin, and Tincup districts.

NOMENCLATURE AND DISTRIBUTION: The Mississippian limestones were included with the Devonian limestones and dolomites in the Leadville formation of Eldridge (1894, p. 6), Spurr (1898, p. 22), and Worcester (Crawford and Worcester, 1916, p. 59) and in the Ouray formation of Crawford (1913, p. 61). Kirk (1931, p. 239) recommended that the term Leadville be restricted to the Mississippian deposits. In the present paper the term is used in the restricted sense.

The Mississippian deposits crop out along the western and northern sides of the Sawatch uplift (Fig. 2) and along the southern and western side of Taylor Park.

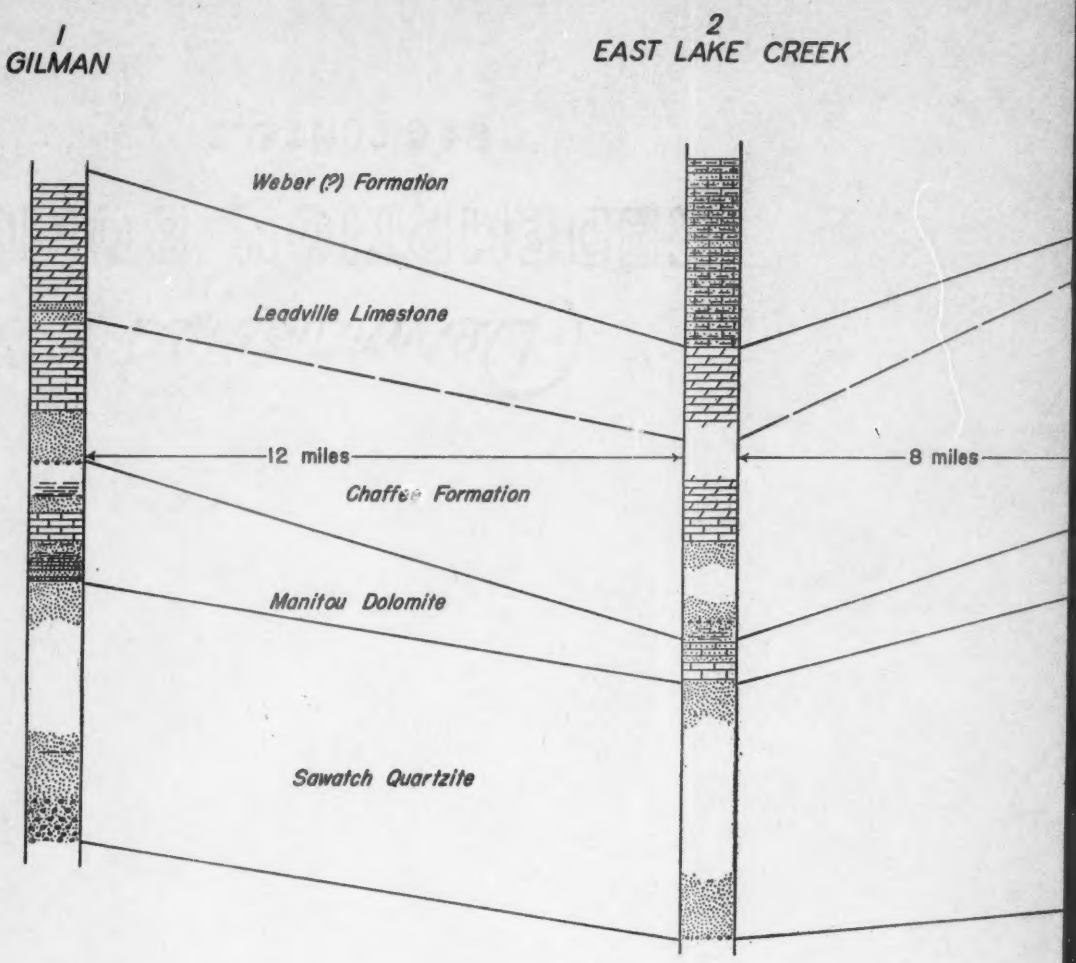
LITHOLOGIC CHARACTER: The Leadville limestone consists of bluish-gray and gray limestones and dolomites. In most places a sandstone or a series of sandy beds is at

the base. Layers of depositional breccia (edgewise conglomerate) occur at and near the base in many sections studied. From the Roaring Fork River to the southern end of Taylor Park the usual sequence is a basal sandy portion, a series of dolomites and limestones, then an upper, nearly pure, limestone (Figs. 6, 7; Pls. 6, 11). North of Aspen the upper limestone is absent in some sections and very thin in others. Most of the upper limestone has apparently been removed by erosion, although possibly it grades laterally into dolomite at the northern end of the range. South of Taylor Park, although limestones predominate, interbedded dolomites again appear near the top of the formation.

The basal sandy phase ranges from a few inches to about 15 feet thick. At the northern end of the range the sandstone is chiefly gray and altered to a quartzite. Farther south it may be yellow, brown, and even reddish brown. In most places a layer of limestone fragments in a matrix of sand immediately overlies the basal sandstone layer. The limestone pieces range from small pebbles to slabs over a foot across. Many are slabby. They are angular but have rounded edges and show signs of weathering. In a few places small pebbles of dark chert or white quartz occur. Other layers of depositional breccia may occur throughout the dolomitic sequence, but for the most part they are strongly developed only near the base of the formation. Good exposures of the basal sandstones and overlying conglomerate were observed at Gilman, Wood's Lake, along the Frying Pan River at the mouth of Lime Creek, along Express Creek south of Ashcroft near the old Express mine, and on the north slope of Mount Tilton.

The base of the Leadville south of Mount Tilton is uncertain, for sandstones or shaly beds occur with limestone conglomerates at several places in the sequence, as mentioned under the discussion of the Devonian-Mississippian boundary. (*See* the sections at the end of the report.) In the Aspen district the basal sandy beds are 2 to 8 feet thick and consist of a layer of sandstone, which may contain numerous fragments of limestone, overlain by thin layers of sandstone and sandy dolomite. They are often recognized in the mine workings by a slight widening of the drifts and irregularities of the walls as the material tends to spall off on exposure to the air. Along the Frying Pan River the basal sandstone and conglomerate is about 8 feet thick, with sandy dolomites above. At Gilman it is about 15 feet thick.

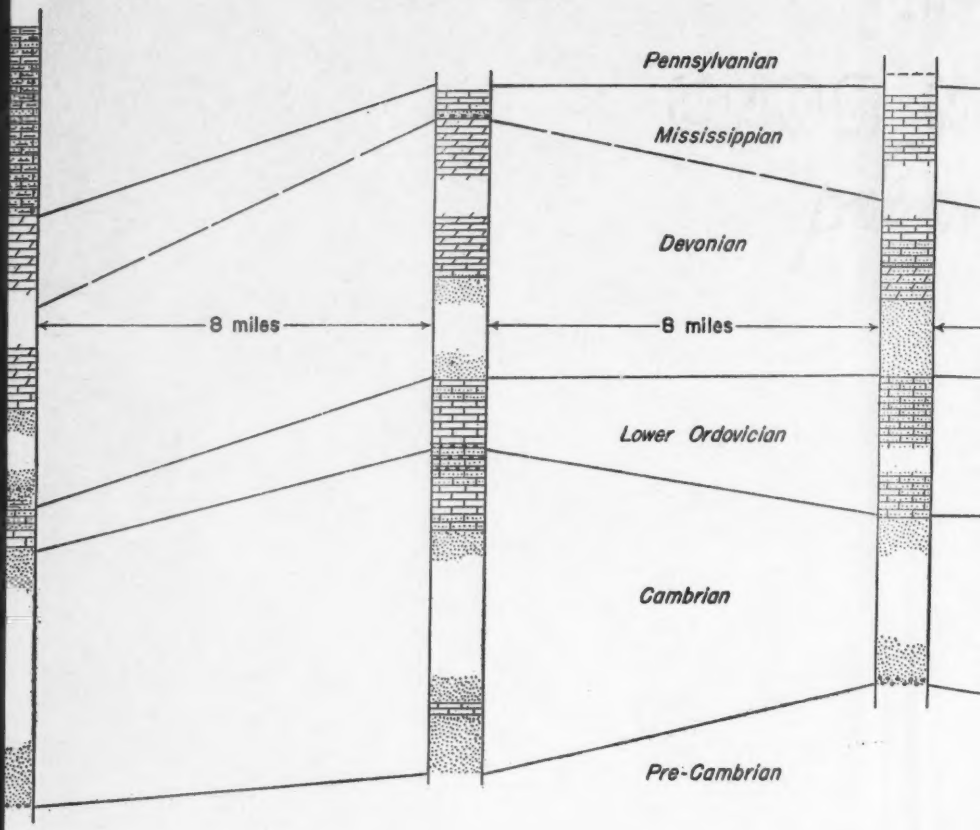
The dolomitic member also shows a usual range in thickness from 60 to 90 feet. On Fossil Ridge, however, it is much thicker and contains abundant limestone interbedded with the dolomites. (*See* beds 29–33, Fossil Ridge section.) There is a similar interbedding of limestone with dolomite in the thick section at Monarch. In the Tincup district this member also consists of alternation of dolomites and limestones, with the limestones predominating slightly. Outcrops were observed along the road to Pitkin, south of Tincup, and on the hill northeast of the El Capitan mine. The beds were seen in the workings of the Gold Cup mine and adjoining properties. Good outcrops occur on the top of Round Mountain, northeast of Tincup, but an unknown amount of the upper part of the formation has been removed by erosion. The same is true on Cross Mountain, west-southwest of Tincup. Along Cement Creek limestones and dolomites alternate, with limestone forming less than half the sequence. From North Italian Mountain to Aspen there is a similar alternation of


1
GILMAN
2
EAST LAKE CREEK
Weber (?) Formation
Leadville Limestone
12 miles
8 miles
Chaffee Formation
Manitou Dolomite
Sawatch Quartzite

2
KE CREEK

3
BRUSH CREEK

4
WOOD'S LA



COMPOSITE SECTIONS OF PALEOZOIC FORMATI

4
D'S LAKE

9
ASHCROFT

SMUGGLER MOUNTAIN

5
FRYING PAN RIVER

Weber(?) Formation

Leadville Limestone

Chaffee Formation

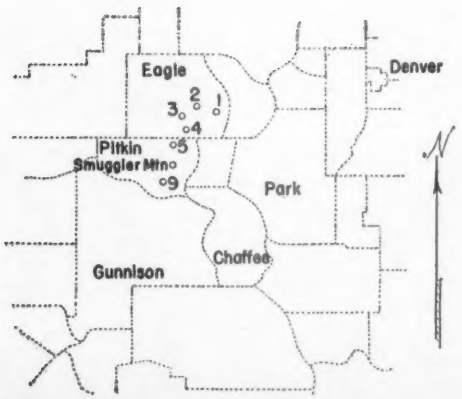
Manitou Dolomite

Sawatch Quartzite

6 miles

12 miles

10 miles



FORMATIONS FROM GILMAN TO ASHCROFT

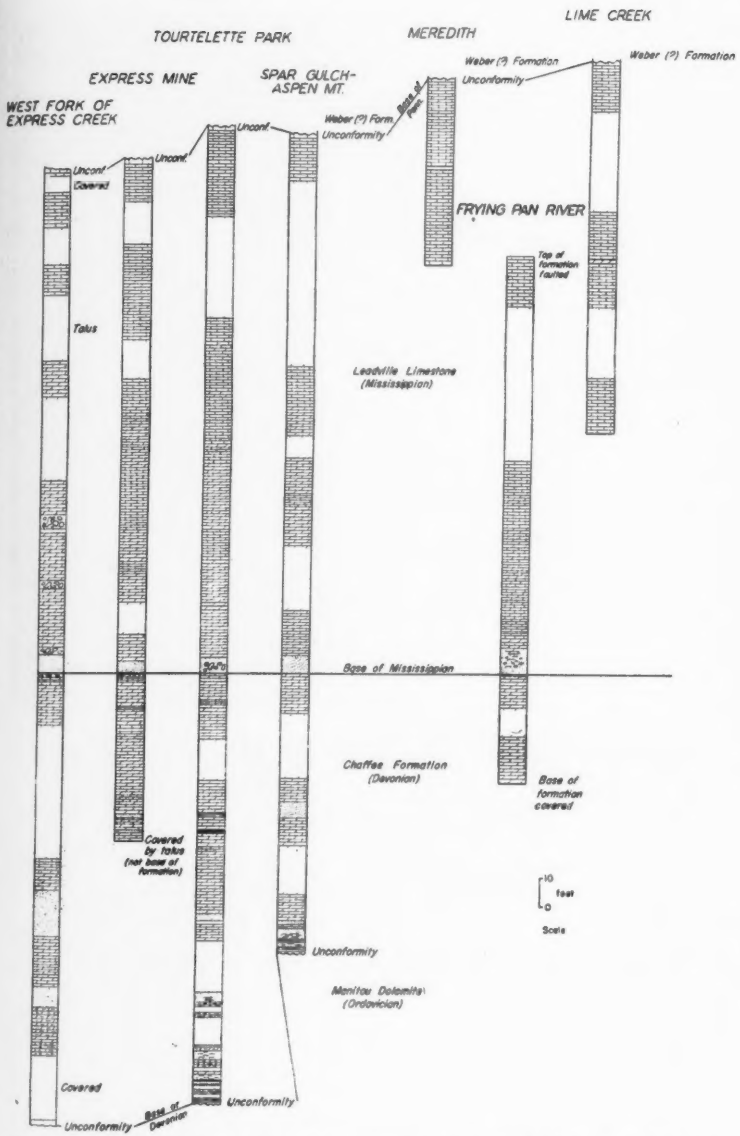


FIGURE 6.—*Sections of Mississippian and Devonian formations in vicinity of Aspen district*

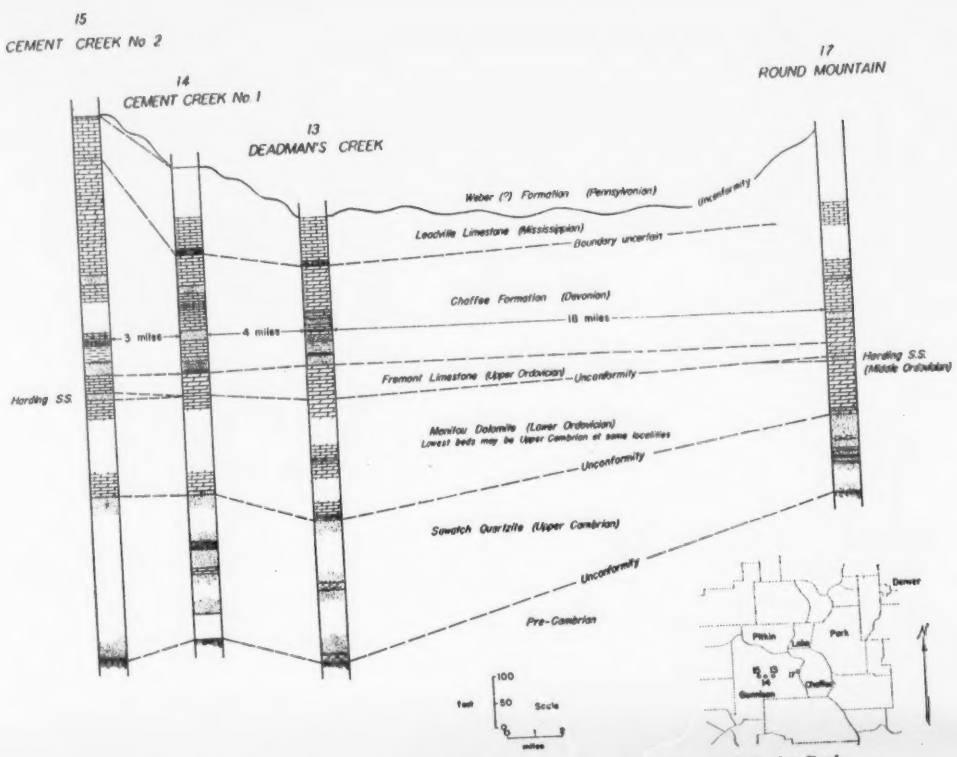


FIGURE 7.—*Composite sections of Paleozoic formations across the south end of Taylor Park*

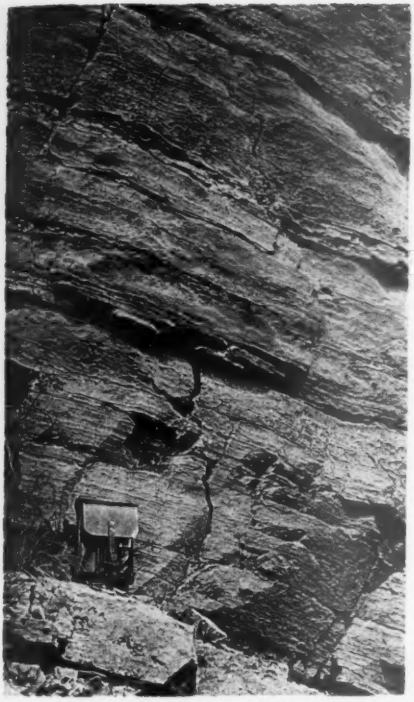


FIGURE 1. MANITOU DOLOMITE
Showing bedding and weathered surface.

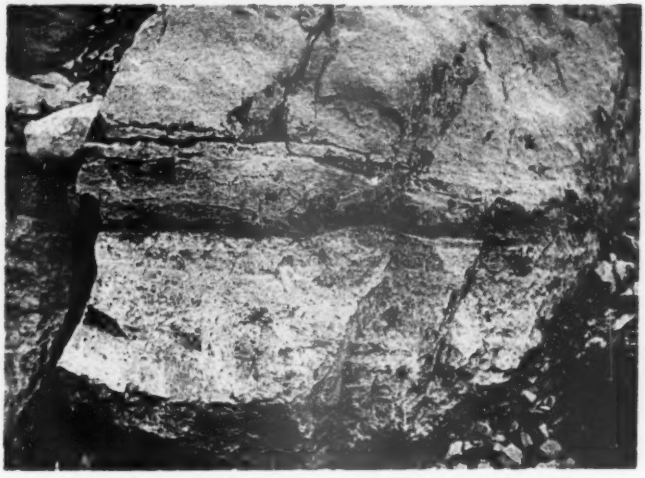


FIGURE 2. CONTACT HARDING QUARTZITE AND FREMONT LIMESTONE
On Cross Mountain

FIGURE 7.—*Composite sections of Paleozoic formations across the south end of Taylor Park*

ORDOVICIAN FORMATIONS

FIGURE 1. DEVONIAN CONGLOMERATIC SANDSTONE
Contains fish plates. Cross Mountain.

FIGURE 2. BASAL DEVONIAN SANDSTONE AND SHALES
Overlying cliff-making Fremont limestone, on Fossil Ridge.

DEVONIAN FORMATIONS

dolomites and limestones, with dolomites becoming more important. In the Aspen district the dolomitic zone is from 75 to 90 feet. Vanderwilt (1935a, p. 227) measured the following section under Castle Butte, at the southern end of Tourtelette Park:

	Feet
Massive limestone	70
Dolomite	1.5
Limestone	3.0
Dolomite	16.5
Limestone	11.0
Dolomite	20.5
Dolomite with chert	21.5
Sandy basal beds	8.0

On the hill above the Express mine south of Ashcroft (Fig. 6) about 100 feet of dolomites with interbedded limestone overlies the basal sandy layer and underlies about 60 feet of limestone. The lower 15 to 25 feet of the dolomite may contain numerous nodules and irregular stringers of dark-gray or black cherts. The cherts are strongly developed at Aspen and southward at least as far as Mount Tilton. Similar cherts were observed at this general horizon, although not always close to the base, on Fossil Ridge, Round Mountain, near Tincup, along the Frying Pan River, and at Gilman.

South from the Roaring Fork River to about the southern end of Taylor Park the dolomites are overlain by a sequence consisting largely of limestones. The dolomite may grade upward into pure limestone or in some places may be separated by a sharp contact. At many places in the Aspen district thin layers and lenses of dolomite occur in or between the lower limestones for 20 to 30 feet above the base of the limestone sequence, although in some places the change is abrupt. The lower layers tend to be thin-bedded, but the upper limestones are massively bedded. The limestone is medium- to fine-grained and in most places is bluish gray and weathers to dark blue gray. The weathered surface tends to be smooth, in contrast to the rough surface of the dolomite. The same description applies to the limestones in the sections west of Taylor Park. The limestone ranges from a few feet to about 100 feet thick.

North of the Roaring Fork River the limestone disappears beneath the unconformity at the base of the Pennsylvanian but reappears near the Frying Pan River and extends northward at least as far as Wood's Lake, but farther north the upper part of the Leadville consists essentially of dolomite.

South of Taylor Park limestones overlie the dolomitic beds and become very thick at the southern end of the range. However, dolomites again appear as beds and lenses at and near the top of the formation.

Dark-blue to black cherts are abundant in the limestones at certain horizons, especially south of Taylor Park, and are very abundant in the Monarch district and along Fossil Ridge. The cherts are rounded nodules and irregular masses, parallel to the bedding.

Thin oölitic to pisolitic layers and lenses occur in the upper part of the limestone beds at many localities. They are about 3 feet below the top of the Leadville along Cement Creek (bed 58, Cement Creek section No. 2), about 20 feet below the top of

the Leadville on the northeast side of Taylor Peak and at several horizons in the upper part of the limestone beds on Richmond Hill, at the southern end of Tourtelette Park, along the Frying Pan River, and along Lime Creek to Wood's Lake. Some of the material is a true oölite composed of small spherical masses with radiating crystalline structure. Most of it, however, is an algal pisolite, composed of rounded dark algal pellets in a light matrix (Pl. 9, fig. 2). Some of these show irregular concentric layering; many consist of masses of tiny tubes irregularly entwined (*Girvanella*). A few show structures characteristic of the genera *Mitcheldeania* and *Ortonella* (Johnson, Mss.) which occur abundantly in some of the Mississippian limestones of England. The light-colored matrix around the algal pellets contains abundant Foraminifera among which the genus *Endothyra* is most common. At some localities (Meredith and Lime Creek) the pisolites are truly foraminiferal-algal limestones (Pl. 9, fig. 2).

THICKNESS AND UNCONFORMABLE RELATIONS: The Leadville limestone ranges from 20 to 500 feet thick and is thickest at the southern end of the range (Fig. 7; Pls. 6, 11). The thickness observed at the localities studied is as follows:

	Feet
Red Cliff	129
Gilman	143.0
East Lake Creek	140
Brush Creek	35.0
Wood's Lake	174.5
Smuggler Mountain	65
Aspen Mountain	120
Tourtelette Park	158
Richmond Hill	175
Express Creek (Ashcroft)	165.8
Mount Tilton	92.4
North Italian Mountain	171.7
Cement Creek 1	159
Cement Creek 2	288
Deadman Creek	more than 89
Cross Mountain	more than 56
Round Mountain	more than 134
Tincup	285
Fossil Ridge	515
Monarch	375

At a few localities south of Mount Tilton the differences in thickness may be due to uncertainty in the Devonian-Mississippian boundary, but most of the variation must be due to differences in original deposition and in the amount of rock removed by post-Mississippian erosion.

The Leadville rests unconformably on the Chaffee below and is separated from the overlying beds by another unconformity. The character of the Leadville deposits in the various sections studied suggests that deposition may have begun at the southern end of the area before it did farther north and may have persisted there longer. However, erosion must be responsible for a large part of the variation in thickness. The unconformity at the top of the Leadville limestone indicates a time of active erosion during which large but varying amounts of the older deposits were removed. The upper layer or layers of the Leadville show staining and other signs of weathering and erosion. In many places the upper surface is irregular, and in a few it has been cut by sink holes and caverns later filled by Pennsylvanian deposits. At Aspen the contact surface is very irregular and can be seen clearly in some of the

FIGURE 1. CLIFF OF LEADVILLE LIMESTONE
On Lime Creek at mouth of Little Lime Creek.

FIGURE 2. ALGAL FORAMINIFERAL LIMESTONE
From upper Leadville limestone, Lime Creek at mouth of Little Lime Creek.

MISSISSIPPIAN LEADVILLE FORMATION

FIGURE 1. INTERBEDDED SANDSTONES AND SHALES
Weber (?) formation, near Minturn.

FIGURE 2. CALCAREOUS ALGAE, *Stylophycus radiatus* JOHNSON
From lower Weber (?) shale on Lime Creek.

PENNSYLVANIAN WEBER (?)

mine stopes in Aspen Mountain, where the upper part of the Leadville was replaced by ore and has been mined out up to the Pennsylvanian Weber (?) formation. Rolls, irregular depressions, and funnel-shaped sinks had been eroded into the limestone. Spurr (1898) considered this a fault contact, but the work of D. P. Rolfing, of Aspen, and that of the writer in 1931, 1934, and 1937, and of Vanderwilt in 1933 definitely proves it to be an unconformity.

The mine workings in Smuggler Mountain reveal the character and amount of erosion during the post-Leadville—pre-Weber (?) interval. Small irregular masses of limestone up to 25 or 40 feet thick occur between the shale of the Weber (?) formation and the dolomite of the Leadville in the Bushwacker Mine. Smaller masses occur in the Park Regent mine, but the limestone is absent from the Park Regent to the Molly Gibson mine along the Roaring Fork River. A little farther south it appears in the mines of Aspen Mountain, and northward from the Bushwacker the limestone occurs regularly above the dolomite for a number of miles. Some of these limestone masses form lenses or islands of good ore in those mines.

In the same mines the Weber (?) formation contains basal conglomerates which are not uniformly developed or distributed but suggest deposition in wide channels cut into the Leadville limestone, the conglomerates occurring between the irregular masses of limestone previously mentioned. The conglomerate is composed of well-rounded pebbles, cobbles, and even small boulders of rocks belonging to all the pre-Pennsylvanian formations down to and including the pre-Cambrian. The miners called these basal conglomerates "rubble." In the No. 1 Smuggler tunnel well-rounded granite boulders were up to 16 inches across in this "rubble." Pebbles of Leadville limestone are locally abundant in the conglomerates which range from a few feet to over 100 feet thick; the maximum thickness was observed in the No. 2 drift from the Clark Tunnel. Locally, ore filled in between the pebbles, and the ore-bearing solutions altered some pebbles.

Rolfing (personal communication, July 26, 1937) reports a pre-Weber (?) channel in the Best Friend mine near Tourtelette Park, where the upper limestone member of the Leadville immediately under the shale of the Weber (?) formation is only about 4 feet thick but thickens abruptly on either side. The channel contains basal conglomerate of the Weber (?) formation.

These facts indicate that pre-Weber (?) erosion removed a considerable part of the Leadville limestone, and not very far from Aspen it must have cut down into the pre-Cambrian by the beginning of Weber (?) time.

CONDITIONS OF DEPOSITION: The rocks included in the Leadville limestone suggest sediments deposited in relatively shallow marine waters with adjacent lands quite low and probably covered with calcareous rocks. The thin bedding, the interbedded layers and lenses of dolomite, and the abundance of chert nodules suggest deposition in shallow waters rather close to land. Ripple marks on the surfaces of some of the lower beds also indicate shallow deposition. The upper beds with their thicker layers and greater amount of nearly pure limestone suggest deposition somewhat farther from land than the lower beds, and in probably slightly deeper water. The fossils observed—corals, calcareous Algae, and Foraminifera—fit into this picture. The dolomites and cherts in the uppermost layers of the thicker sections suggest a shallowing of the water, possibly as a prelude to sea withdrawal.

During the early Mississippian the sea advanced apparently from the west or northwest into the southern part of the region now occupied by the Sawatch Range and slowly encroached on the adjoining areas. At their maximum these seas covered much of the present State of Colorado with only relatively small areas exposed in the southern part of the State and along the northern end of the present Front Range. These seas continued until after the middle of the epoch. Then they slowly withdrew, leaving first the northern end of the area, but lingering at the southern end of the present Sawatch Range and in the areas to the south and west.

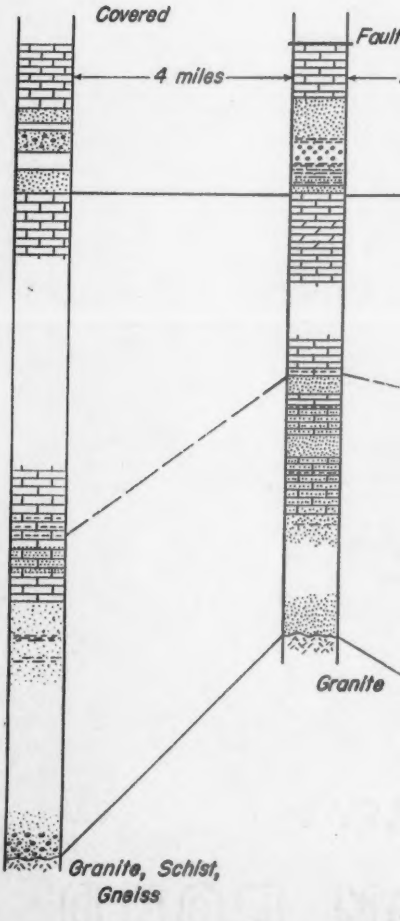
The Mississippian and Devonian dolomites are much alike and appear to have been deposited under such similar conditions that they may be discussed together. In the Devonian beds the thinness of the bedding; the ripple marks on some of the bedding planes; the interfingering and interbedding of dolomites with sandstones, shales, and calcareous shales; the inclusion of sand grains and even small pebbles in the dolomites; together with the occurrence of edgewise conglomerates composed of slabby dolomite fragments in a groundmass of sand, sandy dolomite, mudstone, or limestone, all suggest shallow-water deposition. The edgewise conglomerates show that the material was dolomite when broken and redeposited and suggests original deposition of dolomite, possibly composed in part of materials derived from the older Ordovician dolomites exposed on the near-by lands to sub-aerial erosion and decay. In the Leadville limestone the thin bedding, the interfingering and interbedding of dolomite and limestone, and the abundance of nodular cherts in many of the dolomite layers likewise suggest deposition in shallow water. The fact that dolomite of the same character and having the same relationship with the other beds is present in all sections both in and away from mining districts is strong evidence that the dolomites are original rather than secondary deposits. Spurr (1898) believed that the thin dolomite layers in the lower 20 to 40 feet of the Leadville were of hydrothermal origin, but Vanderwilt (1935a, p. 238–239) disagrees. Evidence leads the writer to agree with Vanderwilt. The sections studied extended over 100 miles. Some were obtained in mining districts, but at least half were not. Yet no appreciable difference in the amount of dolomite at the various horizons was observed in the mining districts. In the Aspen district itself the section differed little in appearance and character from those of areas to the north and south, a strong indication that in general the dolomites have not resulted from local mineralization. Secondary dolomite occurs at Aspen along and near the faults and ore deposits, but as irregular masses and not forming the large bedded deposits. Silicification has been considerable, producing a rock that strongly suggests weathered dolomite. This has probably given rise to an over-estimate as to the amount of secondary dolomite resulting from the action of mineralizing solutions and related in general origin to ore-depositing solutions.

LEADVILLE LIMESTONE AS AN ORE-BEARING ZONE: The Leadville limestone is one of the important ore-bearing formations of the Sawatch Range. In the Monarch and Tomichi districts it is not so important as the Lower Ordovician Limestones, but Crawford (1913, p. 208) reports small deposits in the formation (Ouray of Crawford's nomenclature) on Monarch Hill.

At Tincup, ore occurs at several horizons in the Leadville along and near contacts of the limestone with the overlying and underlying dolomites (Goddard, 1936, p. 566).

9 ASHCROFT

10 TAYLOR PASS



12

11 NO. ITALIAN MOUNTAIN

MOUNT TILTON

10

OR PASS

Fault

3 miles

3 miles

9 miles

Leadville Lime
(Mississippian)

Chaffee Forma
(Upper Devonia

Fremont Lime
(Upper Ordovi

Manitou Dolomite
(Lower Ordovician)

Lowest beds may be Cambri
localities

Fault

Granite

Sawatch Quartzite
(Upper Cambrian)

Pre-Cambrian

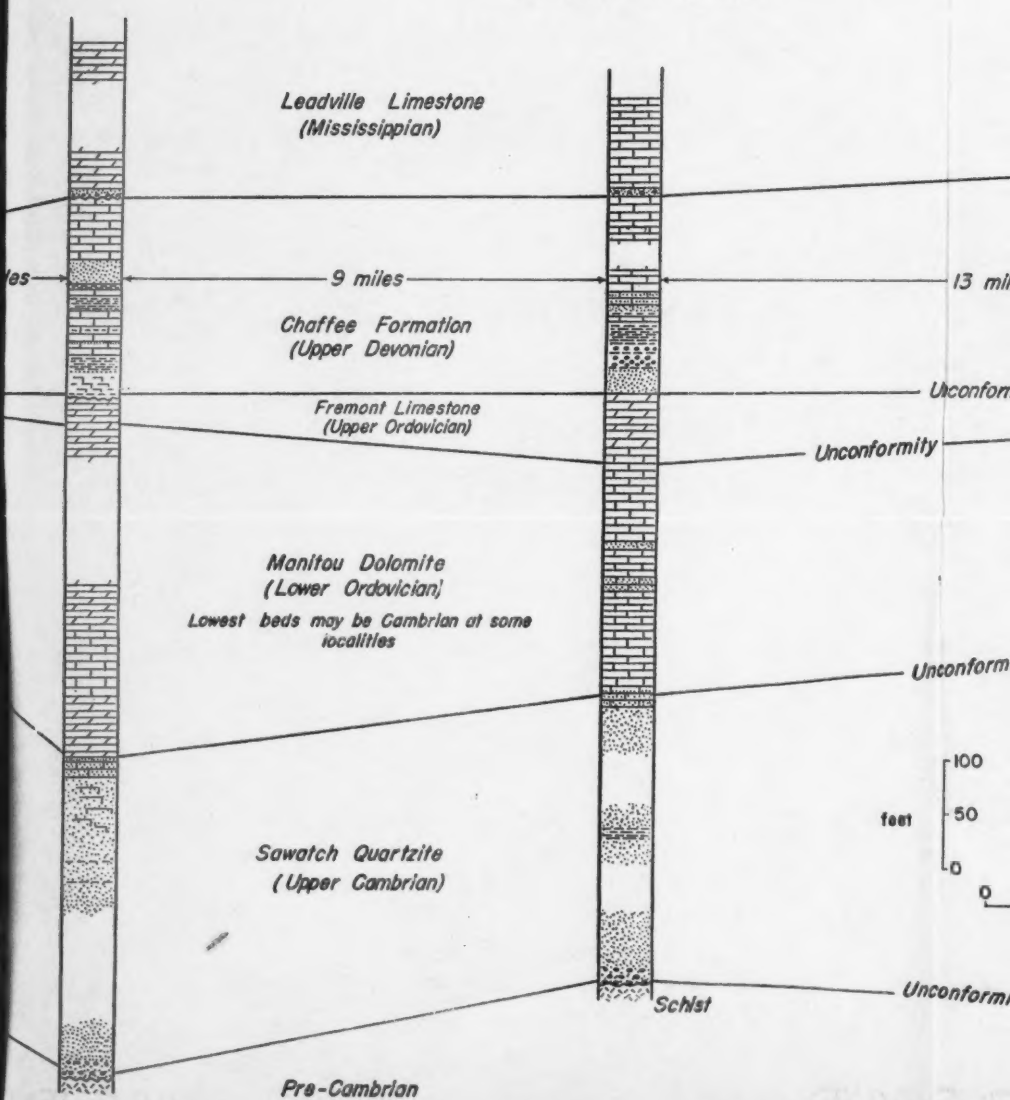
COMPOSITE SECTIONS OF PALEOZOIC

12

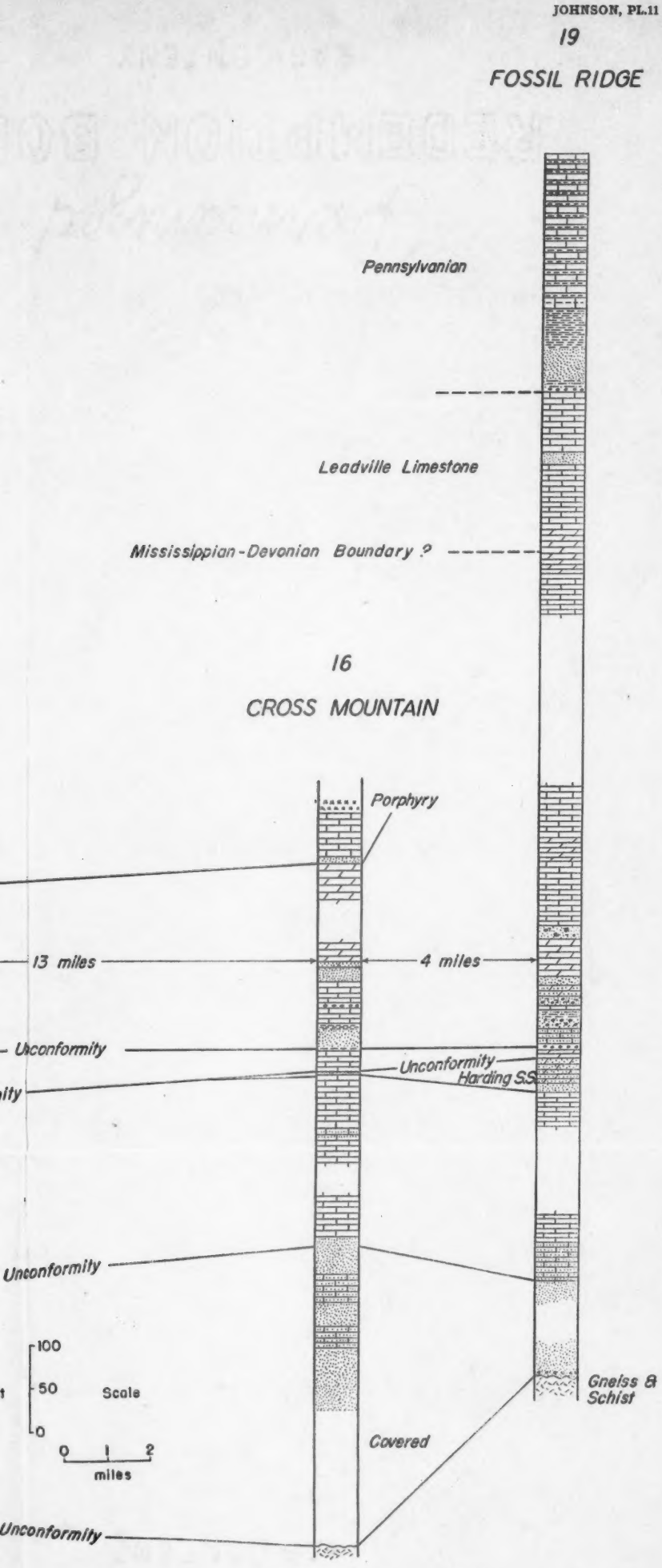
ITALIAN MOUNTAIN

13

DEADMAN'S CREEK



OMPOSITE SECTIONS OF PALEOZOIC FORMATIONS FROM ASHCROFT TO FOSSIL RIDGE


19
FOSSIL RIDGE
Pennsylvanian
Leadville Limestone
Mississippian-Devonian Boundary ?
16
CROSS MOUNTAIN
Porphyry
13 miles
4 miles
Unconformity
Unconformity
Harding S.S.
Unconformity
100
50
0
Scale
0 1 2
miles
Covered
Gneiss & Schist
Unconformity

In the Aspen district the Leadville has been the important ore-bearing formation; its upper part has been particularly rich in deposits. Although, as on Aspen Mountain, silver sulphides are widely disseminated in the limestone, the main ore horizons seem to be along and near the boundary between an upper limestone member and an underlying dolomite member of the Leadville at points where the interbedded dolomite and limestone near their contact have been brecciated as a result of cross-faulting or of folding. Locally, ore deposition was concentrated in the upper part of the limestone along and close to the contact with the overlying Pennsylvanian formations.

AGE AND CORRELATION: Fossils in the Leadville along the Sawatch Range are more sparse than expected, considering the character of the rocks.

Eldridge collected fossils from the black dolomite south of Monarch, and Girty (1903, p. 273, 285, 531) identified them as: *Syringopora aculeata* Girty, *S. surcularia* Girty, and *Spirifer centronatus* Winchell.

Crawford (1913, p. 65) obtained the following from supposedly the same bed: *Zaphrentis* sp., *Streptelasma* ? sp., *Syringopora aculeata* Girty, *S. surcularia* Girty, and *Spiriferina solidirostris* White.

In the Gold Brick district, Crawford and Worcester (1916, p. 63) obtained *Syringopora aculeata* Girty, *S. surcularia* Girty, *S.* sp., *Bellerophon* sp., and *Straparollus* ? sp.

Three small collections were obtained during the season of 1934 from horizons high in the formation and were identified by G. H. Girty as follows:

Collection J-387, Gold Hill, S.W. Tincup; *Syringopora aculeata* Girty, *Triplophyllum* sp., *Cyathophyllum* ? sp., *Echinocrinus* sp., and *Spirifer* aff. *S. centronatus* Winchell.

Collection J-387-F, Gold Hill, S.W. Tincup (about 40 feet higher stratigraphically than J-387): *Syringopora aculeata* Girty, *Triplophyllum* sp., and *Cyathophyllum* ? sp.

Collection J-410, S.W. end Tourtelette Park: *Cyathophyllum* ? sp. *Spirifer* sp. and *Euomphalus* sp.

During 1937 several other small collections were obtained from beds at or close to the top of the formation. The identifications furnished by James S. Williams are listed by locality in Table 8.

Williams (personal communication, February 1938) stated:

"The Mississippian collections are all from the Leadville limestone. They suggest that fossils are rare and poorly preserved in this formation in the Aspen region, as the collections are small and few of them contain more than one or two specimens that are well enough preserved for positive determination. Corals and gastropods are the most common fossils. For many years the Carboniferous corals have been neglected. Recent revisional work has resulted in the establishing of many genera which are based on much finer details of internal structure than previous genera, and also on ontogenetic development, so that their correct identification ordinarily requires several complete or nearly complete, specimens. Few of these genera are based on material from the western United States. It has been impossible to make positive identifications of many of the horn corals because of the combination of detailed requirements for the genera and incomplete or fragmentary specimens in the collections.

"The two species of colonial corals, *Syringopora surcularia* Girty, and *Syringopora harveyi* White are characteristic Mississippian species in this region, but both have been listed from younger rocks in other regions. Both are slightly more suggestive of lower than of upper Mississippian age.

"The gastropods in general form and size resemble common Mississippian species and also are more suggestive of lower than of upper Mississippian age, as the most common species were described from the Madison limestone or formations of about the same age.

"All the collections that contain anything other than horn corals are predominantly of species

previously known from the Leadville limestone. They contain no new elements that suggest that the beds they came from are younger than the age ordinarily assigned the Leadville.

"These collections, I believe, are too meager and too few to support any subdivisions of the Leadville based on paleontology. The occurrence of the *Syringoporas* in the collections only from the upper 10 feet of the sections in Express and Lime Creeks, may possibly have some local significance."

TABLE 8.—*Fossils of the Leadville limestone*

Locality	8460	8462	8463	8466	8468	8474	8459	8458	8465	8464	8473	8469
Foraminifera												
Endothyra baileyi (Hall)											X	
E. sp. undescribed											X	
Corals												
Amplexus? sp. undet.								X				
Caninia sp. undet.	X			X		X		X		X		
Hamalophyllum? sp. A		X										
H. sp. undet.						X		X				
Neozaphrentis? sp. undet.	X											
Syringopora harveyi White		X	X	X								
S. surcularia Girty								X				
Brachiopod												
Composita humilis Girty								X				
Pelecypods												
Schizodus aff. *S. palaeoneiliformis* Herrick									X			
Gastropods												
Bellerophon? sp. undet.												X
Loxonema sp. undet.								X	X			X
Straparolus ophirensis (Hall and Whitfield)				X			X	X				
S. (*Euomphalus*) cf. *S. luxus* (White)							X	X				
S. (*Euomphalus*) cf. *S. blairi* Miller							X					
S. (*Euomphalus*) *utahensis* Hall and Whitfield?										X		
Cephalopods												
"*Orthoceras*" sp. undet.							X					

	Bed			
8460,	29, West Fork Express Creek*		8458,	10 (at top), Lime Creek section
8462,	38		8465,	10, Lime Creek section
8463,	38		8473,	4, Meredith quarry section
8464,	37	Express Creek section		
8468,	36			
8474,	30			

* *See* detailed sections at end of report.

Lloyd G. Henbest (personal communication, February 24, 1938) makes the following statement on the Foraminifera from the Meredith Quarry section:

"This limestone has an oolitic appearance, but a large number of the grains are shells of *Endothyra baileyi* (Hall) instead of minute, oolitic concretions. Many of the grains are recognizable as fragmentary or entire but small invertebrate shells, while the remainder are either inorganic or unrecognizable. Practically all of the fossils are surrounded by a thin, dark accretionary layer of nearly the same color as the shells of *Endothyra*. Two or three specimens were identifiable as a new species, probably of *Endothyra* and distinct from *E. discoidea* [Girty, 1915, p. 27], from Batesville sandstone of Arkansas.

"*Endothyra baileyi* is extremely abundant in and very characteristic of the Salem limestone of Indiana. Its range, however, has not been fully studied. From present information, it seems to be restricted to upper Osage and middle Mississippian in this country, but I would want supporting evidence before using the species even closely for correlation."

The algae give little help in correlation; too little is known of their geological range. These fossils were collected from the upper limestones of the formation in the region where the Leadville is thick. The lower dolomitic member can be traced along the Sawatch Range and around its northern end into the Leadville district, where the beds have yielded fossils of late Kinderhook or lower Burlington age. The fossils collected recently suggest lower Mississippian or at most middle Mississippian so that, whereas much if not most of the formation is early Mississippian (late Kinderhook or Burlington), along the southern part of the range the upper beds may represent some middle Mississippian.

The Leadville limestone along the Sawatch Range is equivalent to the Madison limestone of Wyoming and is correlated with those deposits of the Canon City region called the Millsap limestone in old reports (Cross, 1894).

PENNSYLVANIAN SERIES, CARBONIFEROUS SYSTEM

Weber (?) formation.—Pennsylvanian deposits attain great thicknesses and cover large areas in the Sawatch Range and adjoining regions of central Colorado. They include dark marine sediments near the base overlain by a thick series of red beds. The terms Weber (?) and Maroon formations have been applied to them.

NOMENCLATURE AND DISTRIBUTION: The term Weber was applied to the dark shaly series of Pennsylvanian deposits of the Crested Butte quadrangle by Eldridge (1894, p. 6) and in the Aspen district by Spurr (1898, p. 30). The name Weber was apparently derived from the Weber quartzite of the Wasatch Mountains of Utah, with which a correlation was made that now seems doubtful. In the Monarch district these beds were named the Garfield formation by Crawford (1913, p. 66); the name Garfield is, however, preoccupied. The writer has traced the formation along the Sawatch Range and around the north end of the uplift into the Leadville district (Johnson, 1934, p. 27). In the Leadville district the name Weber has been retained for the convenience of the mining public, but a query has been added to express the doubt regarding its appropriateness (Emmons *et al.*, 1927, p. 38). Therefore the designation "Weber (?) formation" is also used in the Sawatch Range.

The map (Fig. 2) shows the general location of the outcrops. Good exposures are rare and usually small on account of the poor resistance of the deposits. In many places they are covered by vegetation.

GENERAL FEATURES: The formation consists mainly of dark shales with interbedded limestones and sandstones. Some beds of the shale may be sandy, and others calcareous; all are quite carbonaceous. Thin seams of impure coaly material were observed at a few places in the Aspen district and near Minturn.

The limestones are usually thinly bedded, quite impure, and dark gray to black. A few show an oölitic to pisolitic structure. Locally they are altered to a black or variegated graphitic marble. Calcareous concretions and limestone lenses occur at certain horizons of the shales.

The sandstones vary considerably in composition and texture. At the base of the formation there is in most places a coarse to conglomeratic sandstone, locally a definite conglomerate. The coarsest materials in the conglomerate were granite boulders over a foot in diameter in the mines of Smuggler Mountain at Aspen. The

sandstones within the shales and limestones are fine-grained. Near the top of the formation, however, they are coarser. Some beds are quite arkosic; others consist mainly of quartz grains.

Usually the Pennsylvanian beds rest on an eroded surface of the Leadville limestone. This surface may be nearly smooth or may be quite irregular as a result of stream channeling and the formation of sink holes and caverns in pre-Pennsylvanian time. On Fossil Ridge the contact is slightly irregular. In the mines of the Aspen district there are pronounced irregularities along the contact. Here the Weber (?) sediments formed a blanket impervious to ore-depositing solutions. Consequently in some places the limestones and dolomites beneath the contact were highly mineralized; where the Weber (?) formation is removed by mining operations the old contact surface is exposed. Pitlike depressions 3 to 5 feet deep and 12 to 30 feet wide were observed. The best exposures of the contact were in stopes in Aspen Mountain. Spurr interpreted this as a bedding fault, which he called the Silver fault (1898, p. 30–33, 71–72).

At the northern end of the range, on the north side of Gore Creek in the Minturn quadrangle, the Pennsylvanian overlaps the pre-Cambrian (Lovering and Johnson, 1933, p. 368).

LITHOLOGIC CHARACTER: At Monarch, Crawford (1913, p. 67) recognized three general divisions of the Weber (?) formation (Garfield formation of his nomenclature): (1) a basal quartzite or conglomerate overlain by black shales with a few comparatively thin strata of quartzite and impure limestone; (2) a series consisting chiefly of interstratified limestones and black shales, for the most part rather thin-bedded; (3) a thick series of shale, shaly limestone, quartzite, and sandstone (Pl. 10, fig. 1). The writer (Johnson, 1934, p. 28) has described somewhat similar divisions in the Weber (?) of the Mosquito Range. During the present work similar divisions or portions were recognized at various points along the range. The boundaries are not well defined due to gradation.

(1) Lower division: Basal conglomerate and sandstones overlain by black shales comprise the lower or shale division. At the base of the formation in most places there is a coarse sandstone or basal conglomerate. It is well developed at Monarch.

At Garfield, about 6 miles east-northeast of Monarch, however, about 14 feet of shale occurs at the base, with quartzites and more shale above (Crawford, 1913, p. 67). On the west side of the prong of Fossil Ridge that forms the divide between Boulder and Comanche creeks other conglomerates and sandstone beds are at the base of the section.

Along Cement Creek the base of the formation is not well exposed. The lowest beds consist of dark-gray sandy shales containing large sand grains and a few small, well-rounded pebbles of chert.

On the northeastern side of Taylor Peak where the west fork of Express Creek heads in a small cirque, the lower part of the Weber (?) is exposed. A small amount of sandy material at the base is overlain by 18 feet of dull black shale, and this in turn by about 40 feet of black shale containing thin limestones and nodular masses and irregular layers of algal limestones and then by at least 350 feet of black shale. In the Aspen district, at most localities visited, a definite basal conglomerate con-

tains abundant pebbles and partly rounded fragments of chert; irregular slabs, fragments, and pebbles of limestone; and quartz sand. This conglomerate ranges from a few inches to several feet thick. The overlying shales may contain small chert pebbles and streaks of limestone fragments for several feet higher up. In the Mayflower Tunnel the Leadville-Weber (?) contact is a very undulating surface with pitlike depressions several feet deep. Here the basal beds consist of a black sandy shale containing large, angular or slightly rounded pieces of Leadville limestone. The workings in Smuggler Mountain reveal more or less rounded limestone fragments within the shale up to 40 feet above the contact. No good outcrops of the lower part of the formation were observed between Woody Creek and East Lake Creek, but the basal conglomerate and sandstones appear to be missing, the deposits consisting mainly of shale with a few thin limestones. At the northern end of the range basal sandstones and conglomerates again occur.

Upon the basal conglomerates and sandstones in most districts studied lies a series of black shales usually highly carbonaceous with a rather dull luster. Some beds are slightly sandy. The majority are not calcareous, although streaks of calcareous shale and impure shaly limestones do occur. This is in contrast with the black shales of the middle division, many of which are calcareous and have a brighter luster. Locally certain layers become so carbonaceous as to form streaks of impure coaly material, as in the mine workings in Smuggler Mountain southeast of Aspen, in prospect holes along Express Creek south of Ashcroft, on the south slope of Taylor Peak, along the Eagle River near Minturn, and near Red Cliff. Spurr (1898, p. 30) mentions thin beds of impure coal but gives no localities; they may belong in the middle division. None of these coaly layers was sufficiently pure or large to be of commercial value.

Numerous nodular masses of algal limestone (Pl. 10, fig. 2) were found along Lime Creek about half a mile north of the Frying Pan River and are quite abundant at a number of horizons in a zone about 50 feet thick (Johnson, 1940, p. 589).

At the northern end of the range these shales tend to become sandy and contain numerous streaks, lenses, and thin beds of sandstone (Pl. 10, fig. 1).

The lower division shows a considerable range in thickness; at Monarch it is about 750 feet. It thins to the north and is quite thin along Cement Creek and in the Aspen district. Along the Frying Pan River it is about 200 feet thick. Toward the northern end of the range it becomes slightly thicker, attaining 250 to 300 feet along the Eagle River.

(2) Middle division: The middle division consists of shales with interstratified limestones. The shales are dark gray to black. Many are calcareous, and a few layers are highly carbonaceous. Locally there are sandy streaks or even thin sandstones. However, sandy layers are rare in this division, except at the northern end of the range. The limestones are dark gray to black, generally argillaceous or carbonaceous. The bedding is usually rather thin, although some beds are thick.

In the Monarch district the division is represented by about 200 feet of alternating limestones and shales. The shales are more or less calcareous and constitute more than half the deposits. The limestones are blue black to black and are rather thinly bedded. Along Cement Creek a similar sequence of black shales with interbedded

limestones occurs. The percentage of limestones and highly calcareous shales seems slightly less than at Monarch, whereas the percentage of highly carbonaceous shale is greater. On Fossil Ridge about 165 feet of alternating shales and limestones is exposed that resembles those at Monarch. At this locality all higher beds have been removed by erosion or cut out by faulting so that it is impossible to estimate the original thickness of the sequence. In the Aspen district the lithology is similar—black, at many places somewhat calcareous, shales with interbedded limestones. The shale constitutes more than half the deposits, but the total limestone is quite great. The limestones are dark gray, blue gray, or black; some are dolomitic, and some contain considerable iron carbonate, although this may be of secondary origin. Spurr (1898, p. 30) noted that the limestones of the Weber (?) are easily attacked by altering agents. The present work confirmed his observations and showed that the limestones are altered beyond the Aspen district. In this connection the shale of the Weber (?), especially of this division, may be quite solid rock if penetrated beyond the zone of weathering. In many mine workings the shale is a hard rock surprisingly different from the soft, highly weathered surface materials. Indications of the calcareous beds were noted along Woody Creek, along the Frying Pan River, near Wood's Lake (Troutville), and along Brush Creek, but the outcrops were poor, and the thickness and relative amounts of limestone are uncertain. On East Lake Creek the division is about 400 feet thick and contains sandy layers. Around Minturn and Red Cliff some shales of this division are quite sandy, and layers of sandstone are interbedded with the shales and limestones.

The thickness of the calcareous division ranges from 100 feet or less along Cement Creek to 200 feet around Monarch. At Minturn it is about 100 feet thick and in the Aspen district it is about 250 to 500 feet thick.

(3) Upper division: The upper division consists of shales and sandstones with interbedded limestones. Most of the shales are somewhat sandy, though they may be slightly micaceous, and some are quite carbonaceous. Calcareous shales are rare. The shales range from light gray to black, and locally some are brownish. The sandstones may be thick or thin, lenticular or quite continuous, fine- to coarse-grained. They may consist of nearly pure quartz sand or may be very arkosic or micaceous. They may range from light gray to black but are usually grayish. The bedding may be thin to very thick.

At Monarch these beds constitute a sequence nearly 1800 feet thick of shale, shaly limestone, and sandstone. Some sandstones are altered to quartzites. The lower half of the sequence is more calcareous than the upper which contains more sandstones. The thickness of individual beds ranges from that of thin streaks to over 20 feet. In the Aspen district good outcrops of the sandy division were studied only along Woody Creek, at the north end of the district. Here the Weber (?) is faulted, and estimation of the thickness is difficult; the rocks are shales and sandy shales with interbedded thin sandstones and limestones. Along East Lake Creek is several hundred feet of sandy shale, with a few thin layers of interbedded shaly limestone and near the top some sandy gypsiferous beds. In the valley of the Eagle River near Minturn the sandy beds are represented by a thick sequence of sandstones with breaks of shale and sandy shale. Limestones are scarce, but streaks and

lenses of conglomerate are present. Along Turkey Creek, east and northeast of Red Cliff, sandstones, grits, and conglomerates comprise over 90 per cent of the section, shales are almost absent, and limestones are few.

Lateral variation is characteristic of the upper division which is quite sandy at Monarch, more shaly in the Aspen district, and mainly coarse sandstones along the Eagle River at the northern end of the range. Northeast of Red Cliff the beds are coarser and the sequence thicker. West of Minturn the upper beds grade into gypsiferous sandstones and gypsums which form the lower part of the gypsum series still farther west.

(4) Resumé: With the exception of a basal sandstone or conglomerate, which is usually present, the beds along Cement Creek and around Taylor Park suggest the middle and upper divisions rather than the lower, and the section is correspondingly thinner. In the Aspen district the deposits also suggest the two upper divisions. Between Fulford and East Lake Creek the deposits are mainly black shale with only a few thin limestone beds and relatively little fine sandstone in the upper portion. Along the Eagle River between Minturn and Red Cliff the formation approximates the Monarch section in character with, however, less limestone and calcareous shale and more sandstone and sandy shale.

THICKNESS: Few complete sections of the formation have been obtained, partly on account of the poor outcrops, but largely because attention has been concentrated on the older formations. Another factor is the uncertainty as to where to draw the boundary between the Weber (?) and the overlying Maroon. It has been drawn on the basis of lithologic units, which probably are not of the same age everywhere. The thicknesses obtained range from about 2800 feet in the Monarch district down to 800 or 1000 feet in the Aspen district, and from 1500 to 2000 feet along the Eagle River.

CONDITIONS OF DEPOSITION: Present information indicates that the Pennsylvanian sea advanced over an area that had been subjected to extensive weathering and erosion. The land was reduced to a low elevation and to relatively slight relief. Much of the area was underlain by limestones that had been attacked by solution as well as by running water. Soil was probably abundant in the depressions, and much of the land was covered by vegetation. As the seas advanced, the soil and loose material were reworked and deposited by the waves while additional deposits were brought in by the streams. For a long time (possibly equivalent to late middle and most of late Pottsville of the eastern United States) the seas were very shallow, and the adjoining lands low. Estuaries penetrated into the lands, and swampy coastal strips bordered the sea. The main landmass seems to have been east and north of the area now occupied by the Sawatch Range. During late Pottsville time diastrophism became active, and the lands to the east and northeast (Front Range Highland) were elevated as was another landmass to the south and southwest (Uncompagre Highland). Probably the central Colorado area occupied by the seas sank slowly. Throughout the rest of the Pennsylvanian and much of the Permian these land areas were rising while the basin was slowly sinking. At the same time there were fluctuations of the sea level probably independent of local diastrophism. As a result the first Pennsylvanian sediments consist chiefly of fine materials with coarse sediments

becoming more abundant later. What we now call the Weber (?) formation represents the deposits formed before the period of active uplift of the adjoining lands supplied abundant coarse sediments and during the beginning of that uplift.

WEBER (?)-MAROON BOUNDARY: The Weber (?)-Maroon boundary has been arbitrarily drawn, largely on a lithologic basis, and the horizon used has not been the same in all districts. Eldridge (1894, p. 6) used the first calcareous grits that resemble those in the overlying Maroon. Emmons (1898, p. 10) in the Tenmile district used a massive limestone, the Robinson, as the boundary. Spurr (1898, p. 34) used a gray calcareous bed that differed from the underlying Weber (?) in the absence of carbonaceous matter and the greater coarseness of its materials. The boundary is in any case arbitrary, as at each locality mentioned some sediments of the type characteristic of the other formation are found both above and below the boundary used. In general, however, the term Weber (?) is applied to the black or dark-gray sedimentary rocks that contain much shale, and the Maroon consists mainly of lighter-gray, brown, or red coarse sediments. Actually these sediments grade into each other both laterally and vertically.

Practically no fossils have been obtained from the upper beds of the Weber (?) or from the lower beds of the Maroon. However, patient field work will probably yield fossils, judging from a recent experience with the corresponding beds in South Park (Gould, 1935).

AGE AND CORRELATION: Fossils are abundant in some of the shales and shaly limestones of the middle calcareous unit but are rare elsewhere in the formation. Crawford (1913, p. 69–70) makes the following statement concerning fossils from the Weber (?) (Garfield formation of Crawford's nomenclature) in the Monarch and Tomichi districts:

"The lowest bed in which Pennsylvanian fossils were found is about 750 feet above the base of the formation. Professor Henderson has identified the following genera and species collected between this horizon and one about 200 feet higher:

1. Fenestella sp.
2. Rhombopora lepidodendroides Meek
3. Chonetes geinitzianus Waagen
4. Chonetes sp.
5. Derbya? sp.
6. Productus semireticulatus var. hermosanus
7. Productus inflatus McChesney
8. Productus cora d'Orbigny
9. Spirifer rockymontanus Marcou
10. Spirifer sp., the form commonly referred to S. boonensis Swallow
11. Aviculopecten sp.
12. Pseudomonotis sp.
13. Pleurophorous subcostatus Meek and Worthen
14. Edmondia cf. E. gibbosa Geinitz
15. Calamites sp.

"Nos. 4, 7, 8, 13, and 14 were collected from the upper part of a hard shale bed about twenty-five feet thick; nos. 11 and 12 were found in the talus near by. No. 7 was also found about forty feet higher in the upper part of a shale bed and lower part of an overlying limestone stratum. Nos. 8 and 9 were collected from a blue limestone about six feet higher. Nos. 1, 2, 3, 5, 6, 8, 9, and 10 were collected from what is apparently the same zone near the fault toward the west where the beds stand vertical. The specimens of *Calamites* were found in a black shale near the fault about 200 feet higher stratigraphically than the lowest fossil-bearing horizon."

Crawford and Worcester (1916, p. 65) obtained in the Gold Brick district, probably from near the base of the middle division, the fossils listed under the following names, which were identified by Junius Henderson.

Cranía sp.
Orthotichia schuchertensis Girty?
Chonetes sp.
Productus nebraskensis Owen?
P. cora D'Orbigny
P. sp.
Marginifera haydenensis Girty
Spirifer boonensis Swallow?
Squamularia perplexa (McChesney)
Composita subtilita Hall?
Bellerophon sp.
Orthonychia cf. *O. acutirostre* (Hall)

Vanderwilt (1935b, p. 1676) obtained fossils from the "Weber shale" along Cement Creek. They were studied by G. H. Girty, of the U. S. Geological Survey, who identified the following forms:

Lophophyllum profundum Milne-Edwards and Haime
Echinocrinus sp.
Crinoid stems and plates
Chonetes aff. *C. granulifer* Owen
C. aff. *C. geinitzianus* Waagen
Productus coloradoensis Girty
P. aff. *P. pertenuis* Meek
Spirifer opimus Hall
S. sp.
Spiriferina aff. *S. subspinosa* Weller
Nucleospira n. sp.
Composita subtilita Hall

They were obtained from a horizon about 250 feet above the base of the Weber (?).

During the present work fossils were obtained from several localities. From a locality of lower Pennsylvanian age, about 500 feet above the base of the Weber (?) on East Lake Creek, about sec. 10, T. 6 S., R. 82 W., Eagle County, (U. S. G. S. Collection 8461), J. S. Williams identified:

Lophophyllum profundum (Milne-Edwards and Haime) Crinoid columnals
Chonetes (*Lissochonetes*) *geinitzianus* Waagen
"*Productus*" (*Cancrinella*) *boonensis* Swallow
"*P.*" (*Linoproductus*) *prattenianus* Norwood & Pratten
"*P.*" (*Dictyoclostus*) *coloradoensis* (Girty)
Marginifera ingrata Girty
Spirifer (*Neospirifer*) *dunbari* King
S. occidentalis (Girty), young
Cleiothyridina orbicularis (McChesney)
Composita subtilita Hall
C. subtilita Hall, small var.
Orthonychia parva (Swallow)

Fossils from a horizon about 60 feet above the base of the formation, along the Eagle River just below Minturn, are identified by the writer as follows:

Crinoid stems
Chonetes geinitzianus Waagen
Productus cora D'Orbigny
Marginifera ingrata Girty
Lingula cf. *L. carbonaria* Shumard

A sandstone about 90 feet above the base of the formation yielded poor impressions of plant stems including a small *Lepidodendron*.

Practically all these fossils came from the lower part of the middle division. They indicate a Pennsylvanian age about equivalent to that of the late middle or early upper Pottsville of the eastern United States.

The beds are equivalent to the so-called Lower Sangre de Cristo formation of the Sangre de Cristo Range, to the Weber (?) formation of the Mosquito Range, to at least some of the lower part of the Fountain formation of the Front Range, and to the lower Hermosa of the San Juan region. They would be correlated also with the lower part of the Magdalena group of northern New Mexico.

DETAILED SECTIONS

With the exception of the North Italian Mountain section which was measured by B. S. Butler and C. H. Behre, Jr., the sections recorded here were measured by the writer, assisted by D. H. Peaker, B. O. Prescott, T. Kenney, E. H. Stevens, and H. Mendenhall. Wherever possible the measuring was done with a tape or rod on steep slopes and cliffs; where the slopes were gentle or there were large covered areas transit and stadia were used. On the longer sections the tape results were checked by surveying methods.

The numbers assigned to the sections are used for identification on the charts (Figs. 3–7; Pls. 1, 2, 5, 6, 11). *See* Figure 1 for location of sections:

1. Gilman
2. East Lake Creek
3. Brush Creek
4. Wood's Lake
5. Frying Pan River
6. Spar Gulch
7. Durant Mine
8. Tourtelette Park.
9. Ashcroft
10. Taylor Pass
11. Mount Tilton
12. North Italian Mountain
13. Deadman's Creek
14. Cement Creek No. 1
15. Cement Creek No. 2
16. Cross Mountain
17. Round Mountain
18. Tincup
19. Fossil Ridge
20. Monarch (From Colorado Geol. Surv. Bull.)
21. West Fork Express Creek.
22. Express Mine
23. Meredith
24. Frying Pan River at Mouth Lime Creek.
25. Lime Creek.

Section 1.—GILMAN, COLORADO

T. 6 S., R. 80 W., Eagle County.

Measured by: J. Harlan Johnson, C. H. Behre, Jr., D. Peaker — July 24, 1931

Bed No.	*Description*	*Thickness (feet)*
	Porphyry sill in Weber (?) formation	
	Covered	18.0
	Unconformity	
	Leadville limestone	
45	Dolomitic limestone, light gray to almost black with irregular layers and masses of "zebra lime" and black chert nodules and stringers	110.0
44	Very sandy limestone with fragments of black chert and a few of limestone	8.0
43	Sandy (gritty) quartzite	2.0
42	Limestone conglomerate in a sandy matrix	3.0
41	Light-gray to brown sandstone	2.0
	Unconformity	
	Chaffee formation	
	Dyer dolomite member	
40	Dolomitic limestone, light gray to dark gray, fine-grained; beds medium to thick	38.5
39	Limestone breccia with black fragments	1.8
38	Blue shaly material, suggests gouge?	0.7
37	Fine-grained (sugary), tan-gray dolomite	32.5
36	Tan-gray limestone with numerous coarse quartz grains	4.2
	Parting member	
35	Coarse gritty quartzite, poorly cross-bedded, almost white	37.8
34	Coarse white conglomerate containing pebbles of quartz up to 2 inches	2.3
33	Covered	18.0

Bed No.	Description	Thickness (feet)
32	Red sandy shale with green splotches	3.6
31	Dolomitic sandstone	0.6
30	Red and green shale, thin-bedded	5.5
29	Dolomitic sandstone	1.0
28	Red and green shale, thin-bedded	5.5
27	White quartzite, contains numerous pits, usually brown stained; has well-developed short cross-bedding; at least one bed coarsely arkosic (white feldspar pieces up to ¼ inch); pits may represent weathered feldspar	6.8
26	Soft white sandstone, containing weathered bone fragments	0.3
25	Light-gray quartzitic grit; upper 8 inches a greensand	2.8
24	Green, glauconitic-appearing sand	0.5
23	White gritty quartzite, slightly dolomitic? Shows short cross-bedding	4.0
	Ordovician or Devonian.	
22	Red-brown dolomite, rather thick-bedded; on weathering it has a sandy appearance; contains numerous apparent casts of brachiopods, but nothing determinable found; streaks of greensand on surfaces of some beds	14.0
	Manitou dolomite (Ordovician)	
21	Covered. Appears to be thin beds of soft tan sandstone and sandy shale.	9.0
20	Light-gray dolomite alternating with light-gray sandy shales (dolomites about 8-inch layers). Dolomites have "red cast" markings	8.0
19	Light-gray dolomite	2.4
	Sawatch quartzite (Cambrian)	
18	Thin beds of calcareous, slightly sandy shale, greenish gray when fresh, weathers a light brown; trilobites (*Saukia*) and small brachiopods have been obtained from these beds. These shales alternate with "red cast" beds	10.8
17	Dolomite, somewhat sandy; cream with dark-red, brown, and purplish markings; characteristic "red cast beds"; upper 2½ inches very thinly bedded and sandy; surfaces ripple-marked, with many fucoid markings	6.7
16	Sandstone, almost white, slightly calcareous; markings suggest worm borings	5.2
15	Calcareous sandstone, massive	2.8
14	Calcareous sandstone, thinly bedded	4.6
13	Quartzite, white to pinkish	2.0
12	Calcareous sandstone	1.7
11	Thinly bedded gritty quartzite (2½-inch beds)	12.5
10	Dolomitic sandstone; contains coarse glassy quartz grains, apparently some finer quartz grains, and a dolomitic cement	1.0
9	Gritty quartzite	9.0
8	Hard, irregular, sandy quartzite; looks like a mass of sand-filled breccia	6.5
7	Massive, gritty quartzite	3.2
6	Thin-bedded, white, sandy quartzite in layers 1 to 2 feet thick	43.0
5	Thinly bedded white quartzite alternating with sandy quartzite; thin beds a foot thick in 2-inch layers, thick beds about 2 feet thick	8.0
4	Massive, white quartzite	65.3
3	Soft, shaly sandstone (makes a distinct break along cliff)	2.0
2	Massive white quartzite (surface brown stained)	42.5
1	Conglomeratic quartzite	40.8
	Unconformity	
	Cambrian—pre-Cambrian contact. Section measured generally in a N. 70° E. direction starting in canyon south of incline at pre-Cambrian contact. Pre-Cambrian is a coarse dioritic rock. Contact, which is slightly irregular throughout the region, is relatively smooth at starting point.	

Section 2.—East Lake Creek

Measured in T. 5 S., R. 82 W., Eagle County, Colorado, along the west side of East Lake Creek, starting where a group of large roches moutonnees mark outcrop of pre-Cambrian. (Thicknesses of beds 21 to 25 only approximate. The lower beds were measured more accurately.)

J. H. Johnson
D. H. Peaker

August, 1931

Bed No.	Description	Thickness (feet)
	Weber (?) *formation* (Pennsylvanian)	
25	Gypsum.	
24	Sandstones and shaly sandstones, gray	850.0*
23	Grit, gray, coarse	35.0
22	Shales, shaly limestone, and sandstones, black, fossiliferous; contains the same fauna obtained 180 to 300 feet above base of Weber (?) in Leadville area. Base covered	40.0+
	Unconformity	
	Leadville limestone (Mississippian)	
21	Limestone and dolomites, not well exposed	68.0±
	Unconformity	
20	*Chaffee formation* (Devonian)	
	Dyer dolomite member	
19	Limestones, dark gray, dolomitic; bleaches on weathering to nearly white; beds 6 inches to 1½ feet thick	89.0
18	Limestone, gray, sandy	6.6
17	Quartzite, white, coarse, massively bedded	5.9
16	Dolomite, gray, sandy	4.6
15	Quartzite, white, coarse, with streaks of quartz conglomerate	15.2
	Parting member	
14	Grits and quartzites, white to dark purple; some short cross-bedding	65.0
13	Grit, coarse, pebbly	1.0
12	Sandy shales and shaly sandstone, purplish and gray	13.0
	Unconformity	
	Manitou dolomite	
11	Dolomite, gray to light brown, sandy	11.8
10	Quartzite, dark gray, hard	5.0
9	Dolomite, light gray, thinly bedded	22.6
	Sawatch quartzite	
8	Sandstone, dark gray, calcareous	4.1
7	Quartzite, white; some beds show traces of fossils; slight developments of edgewise conglomerate	7.9
6	Quartzite, white, thinly bedded	18.0
5	Quartzite, white, cross-bedded	8.2
4	Quartzite, white, very massive bedding	71.0
3	Quartzite, white to brown-tan, massively bedded; many worm borings in rock	39.0
2	Quartzite, white, massively bedded	85.0
1	Grit or fine conglomerate	1.8
	Unconformity	
	Pre-Cambrian	
	Note: Mr. Lovering found quartzite float that contained brachiopods usually found near the top of the Cambrian, which suggests the quartzite may take the place of the "Peerless" type of sediment here.	

Section 3.—Brush Creek

In T. 7 S., R. 83 W. probably in secs. 15 and 22, Eagle County, Colorado. Section starts about one mile up creek from fork of trails.

J. H. Johnson
D. H. Peaker
1931

Bed No.	Description	Thickness (feet)
	Leadville limestone (Mississippian)	
26	Limestone, dark blue gray	18.0
25	Quartzite, dark gray blue	5.0
24	Conglomerate, mainly limestone but containing small white quartz pebbles	0.8

* Approximate.

Unconformity

Bed No.	Description	Thickness (feet)
	Chaffee formation (Devonian)	
	Dyer dolomite member	
23	Limestone, dolomitic, dark gray; rather thinly bedded near base but becoming more massive about 25 feet up. Abundant fossils visible on weathered rock surfaces—corals, crinoid stems, large gastropods, and brachiopods, mainly spirifers; coiled gastropods up to 2 inches across, common	137.7
22	Limestone, sandy	6.5
	Parting member	
21	Quartzites, gritty, purplish	12.0
20	Limestone, gray, sandy	2.2
19	Quartzites and sandstones, gray to purplish brown; some beds gritty or a fine conglomerate; strongly cross-bedded	24.9
18	Quartzite, white (grades upward into material above)	57.0
17	Sandstone, gritty, tan	1.8

Unconformity

	Manitou dolomite (Ordovician)	
16	Dolomite, light tan	7.4
15	Dolomites and sandstones, sandy, purplish	11.0
14	Dolomites, tan, gray near top	44.0
	Sawatch quartzite (Cambrian)	
13	Shale, gray, slightly micaceous	1.6
12	Dolomites and sand dolomites with breaks of calcareous shale; all thicker beds are edgewise conglomerate	6.8
11	Small pellet conglomerate	1.0
10	Sandy dolomites with breaks of calcareous shale; surfaces sun-cracked and ripple-marked	7.2
9	Edgewise conglomerate. Smooth flat pieces as much as, 8 inches long with rounded corners embedded in a dolomitic groundmass; "red cast" markings.	2.3
8	Dolomitic sandstones with breaks of calcareous shale; light gray to tan or cream; some thicker layers are edgewise conglomerates	12.7
7	Thin-bedded limestones, calcareous shales, and calcareous sandstones. Many surfaces show ripple marks and fucoid markings; some are sun-cracked. Contains small brachiopods; some beds contain numerous small mica flakes parallel to bedding	6.8
6	Sandy dolomite and dolomitic sandstone, brown-gray; beds 2 to 6 inches thick	27.4
5	Quartzite, white to light gray; beds average about a foot or 15 inches thick	101.8
4	Quartzites, white, massively bedded, beds average over 3 feet thick; show cross-bedding; some layers have abundant worm borings	61.0
3	Dolomitic limestone, thinly bedded	8.2
2	Quartzite, white, massively bedded (beds average about 15 inches thick)	49.4
1	Grit with small pebbles; dark gray	6.0

Unconformity

Pre-Cambrian.

Section 4.—Wood's Lake

1 mile west of Wood's Lake on south side of Lime Creek in sec. 24, T. 7 S., R. 83 W., Eagle County, Colorado.

J. H. Johnson
D. H. Peaker

August 14, 1931

Section starts at pre-Cambrian-quartzite contact on south side of Lime Creek just west of the Lime Bluff. Contact may be a fault contact or a sharp overlap; because the beds are sharply folded here faulting seems most probable. Lowest quartzites exposed, however, are pebbly, almost conglomeratic, and are probably close to base of formation.

Bed No.	Description	Thickness (feet)
	Weber (?) formation (Pennsylvanian)	
	Gray-black, sandy shale and shale.	
12	Black, coaly shale; streaks of impure coal	5.0
11	Covered with float. May be Leadville, but there are no outcrops	17.0
10	Limestone, dark gray, weathering lighter; contains fragments of crinoid stems and other fossils and one layer which is crinoidal-coral limestone	91.0
9	Limestone, dark gray, with a few black chert nodules; massive beds	45.0
8	Limestones, gray, slightly sandy; contains large grains of clear quartz in places, also a few chert fragments; sand not evenly disseminated, but in streaks; pronounced streak at top	18.0
7	Limestone, gray, sandy, with angular fragments of limestone and chert imbedded in it	1.9
6	Quartzite, white	1.6
	Chaffee formation (Devonian)	
5	Limestone, gray, sandy, dolomitic, light gray near base, becoming darker higher up; contains fragments of corals and other fossils; a few large nodules and streaks of white chert about 50 feet above base	131.0
4	Quartzite, coarse and granular, but well silicified; white at base, brownish near middle, and white to pinkish white near top	72.0
	Manitou dolomite (Ordovician)	
3	Dolomitic sandstone or silicified dolomite, weathers brown; badly cracked and silicified (cut by small quartz veins)	130.5
	Sawatch quartzite (Cambrian)	
2	Quartzites, white, medium to thick beds, (average 1 to 1½ feet); a few pebble streaks near base	156.0
1	Quartzite conglomerate, white; quartz pebbles up to ¾ inch mixed with finer material; strongly silicified	5.0
	Pre-Cambrian.	
	Quartz mica schist with bands of horn-blende schist.	

Section 5.—Frying Pan River, Devils Chimney Camp

(Just above mouth of Lime Creek)

By Devil's Chimney Camp on north side of Frying Pan River, in secs. 17 and 18, T. 8 S., RS. 83, 84 W. in Pitkin County, Colorado.

J. H. Johnson
D. H. Peaker

August, 1931

Bed No.	Description	Thickness (feet)
	Chaffee formation (Devonian)	
	Dyer dolomite member	
	Fault—(Thomasville overthrust).	
	Parting member	
	(Possibly some cut out by faulting.)	
22	Quartzite, white to purplish; coarse texture; cross-bedded	24.0
	Manitou dolomite (Ordovician)	
21	Limestone, gray to dark gray, dolomitic; most layers contain silicified fragments of fossils and silicified bands	58.9
20	Limestone, gray; some beds suggest depositional breccias; contains shell fragments	25.0
19	Shale, black	0.4
18	Edgewise conglomerate, dark gray, in a sandy matrix with shell fragments	2.6
17	Quartzite, light gray	1.8
	Sawatch quartzite (Cambrian)	
16	Dolomite, yellow gray	26.0
15	Shale, olive green, limy	0.9
14	Dolomite, yellow gray	1.8
13	Limestone, olive green, shaly	0.8
12	Edgewise conglomerate, light yellow brown, dolomitic. (Well-developed "red cast" markings.)	1.3

Bed No.	Description	Thickness (feet)
11	Sandy limestone edgewise conglomerate, rather coarse, mainly gray, but some beds have red pebbles	8.8
10	Limestone, edgewise conglomerate, coarse and all gray at base; upper 6 inches has small red pebbles; very showy rock	2.5
9	Limestones and calcareous shales, thin-bedded. (Carry numerous small black brachiopods.)	8.6
8	Thin sandstones, light green to tan, interbedded with thin layers of sandy limestone and shale; contains trails of invertebrates	15.4
7	Sandstone, cream, fine-grained	17.5
6	Sandstones alternating with greenish-gray shales and shaly limestones; sandstones beautifully ripple-marked	35.3
5	Quartzite, white	6.0
4	Fault—possibly some quartzite cut out. Quartzite, white	18.0
3	Quartzite, brownish to pinkish-white; texture coarse; at top, a layer of brown sandstone containing flat pieces of white quartzite	43.4
2	Quartzite, rather massively bedded	41.6
1	Quartzite, brownish white with white quartz pebbles	2.6
	Pre-Cambrian—a mica schist.	

Section 6.—Spar Gulch, Aspen Mountain

About S.W. cor., sec. 18, T. 10 S., R. 84 W., Pitkin County, Colorado.

Measured by: J. H. Johnson, H. Mendenhall — July 21, 1937

Bed No.	Description	Thickness (feet)
	Section starts at top of cliff just above (southwest) the old Aspen mine and was measured down the slope of Spar Gulch. Leadville limestone forms a cliff along north side of gulch. Cliff starts almost at top of the Leadville. Rocks are badly fractured, recrystallized, and seamed with secondary calcite, and so on. Locally, upper limestone is altered to a coarse marble by a porphyry intrusion.	
	Leadville limestone (Mississippian)	
24	Limestone, dark blue gray; massive to medium bedding, pronounced bedding plane at base	14.0
23	Limestone, gray; contains fragments of crinoid stems near top; grades into crystalline limestone 20 feet below top; pronounced bedding plane at base	25.0
22	Limestone, dark gray, massive; pronounced bedding plane at base	21.0
21	Limestone, dark blue gray; contains organic fragments; slightly crystalline; fractures contain a carbonate (dolomite or siderite?)	20.8
20	Limestone, dark blue gray, massive; contains numerous horn corals mainly belonging to genus *Caninia*, and fragments of crinoid stems	17.0
19	Covered. Appears to be largely dolomite	18.0
18	Dolomite, gray, weathering light gray; beds medium	13.4
17	Limestone, dark blue gray, mottled. Some mottlings show a concentric nodular banding suggesting an original algal or concentric structure	2.2
16	Dolomite, light gray	1.6
15	Limestone	0.8
14	Dolomite, gray to light gray; medium bedding	17.0
13	Dolomite, dark gray to gray; medium bedding; poorly exposed	36.0
12	Sandstone, light brown, coarse-grained; depositional breccia near top; grades upward into a sandy dolomite; calcareous or dolomitic cement; silicified at base	6.6
	Unconformity	
	Chaffee formation (Devonian)	
11	Dolomite, gray to light gray, beds medium	28.0
10	Dolomite, fine-grained, light gray to yellow gray; thin to medium bedding; a few breaks of gray shale	17.8
9	Sandstone, light gray to light brown, fine- to medium-grained; suggestions of cross-bedding	5.9
8	Dolomites, light gray to yellow gray; thin-bedded	21.0
7	Dolomites, light yellow, impure, muddy, very fine-grained; a few massive beds, the rest thin; breaks of green or green-gray shale	16.2

Bed No.	Description	Thickness (feet)
6	Sandstone, light brown	0.7
5	Dolomite, light gray, fine-grained	1.6
4	Thin-bedded sandstones and sandy shales; surface of beds rippled; a few thin sandy dolomites; some sandy layers slightly micaceous	6.9
3	Sandstone, brown coarse- to medium-grained with a few very coarse grains of quartz, all well rounded	0.8
2	Dolomitic sandstone, light yellow-gray, with fragments and pebbles of gray dolomite	0.4
	Unconformity. A slightly wavy surface	
	Manitou dolomite (Lower Ordovician)	
1	Dolomite, dark gray, medium bedding; surfaces of beds irregular	8.0
	Dolomite, dark gray; beds 6 to 10 inches thick	132.0
	Streaks of gray chert begin to appear about 40 feet below top and become numerous in beds between 90 and 115 feet below top. In lower 20 feet measured thin breaks of black shale occur between bedding planes of the dolomite, which is medium- to thin-bedded. At 125 feet below top much thin streaking of chert on weathered surface suggests replacement of organic material.	
	Bottom of gulch, 140 feet below top of formation. Rest of formation not exposed.	

Section 7.—Durant Mine, Aspen Mountain

Measured in Durant Mine on east-west crosscut about halfway between Cribb fault and Spar fault. It includes part of the Sawatch quartzite, all of the Ordovician Manitou dolomite, and the Devonian Chaffee formation.

Measured by: J. H. Johnson, Rolfing and Butler — June 24, 1937

J. H. Johnson, E. H. Stevens — June 26, 1937

Bed No.	Description	Thickness (feet)
	Leadville limestone (Mississippian)	
	Fault zone (Limestone around faults highly silicified.)	
	About 40 feet of Leadville limestone shows between Aspen fault and limestone-dolomite contact; badly shattered; silicified in varying amounts.	
	Sandy layer (base of Leadville) about 78 feet below limestone-dolomite contact.	
	Chaffee formation (Devonian)	
	Dyer dolomite member	
22	Dolomite, dark gray, beds medium to massive. (Crosscut, stope above.)	24.0
21	Dolomite, dark gray to almost black, beds massive to medium	64.6
20	Sandy dolomite	5.3
	Parting member	
19	Sandstone, quartzitic, dark gray	1.4
18	Dolomite, gray, thin- to medium-bedded	12.8
17	Sandstone, quartzitic, white to light gray; massive beds	7.2
16	Dolomite, dark gray, beds 4 to 13 inches; very thin breaks of shale between some layers	15.8
15	Quartzite, white to yellow, with green shales and calcareous mudstones. Both shales and mudstones are bright green in many places	8.0
14	Calcareous mudstones and dolomites with breaks of sand and green-gray shale	7.0
13	Dolomite, dark gray, thinly bedded with streaks of sand	2.6
12	Sandstone and sandy dolomites, thinly bedded	3.4
11	Sandstone, light brown, thinly bedded	1.0
	Top of Manitou. Unconformity not obvious, boundary nearly straight.	
	Manitou dolomite (Ordovician)	
10	Dolomite, gray to light brown	14.0
9	Dolomites and sandy dolomites, tan to light brown, beds 4 to 16 inches, average 8 to 10 inches	213.0

Bed No.	Description	Thickness (feet)
8	Dolomites and sandy dolomites; beds 1 to 3 inches; thin shale breaks.....	8.0
7	Dolomite, light tan to rich brown; beds 2 to 14 inches thick, average 6 to 8 inches, gray to black shale breaks between layers up to ¾ inch thick.....	60.0
	Sawatch quartzite (Upper Cambrian)	
6	Dolomite and sandy dolomite, with shale breaks and thin sandstones. Dolomite gray to tan; shales greenish-gray to gray, some thin ones black; sandstones brown to red-brown; beds 2 to 6 inches. Some layers show "red cast" effect, apparently a depositional breccia. Drift N-S from crosscut. Top of transition beds.....	14.0
5	Shale, chocolate-colored.....	1.8
4	Shales, greenish gray with interbedded sandy dolomites; mainly shale and sandy shale; dolomite beds up to 6 inches..... A slight break. Apparently very little if any displacement.	14.0
3	Shales, green to gray, slightly sandy, with thin beds of dolomite sands or sandy dolomite; bedding up to 2 inches.....	7.0
2	Dolomite and sandy dolomite; some breaks of shale; bedding up to 10 inches, average 4 or 5 inches.....	29.0
1	Quartzite, banded brown and white, medium- to coarse-grained; some layers slightly arkosic; few layers dark gray to blue gray.....	17.0

Section 8.—Tourtelette Park

On prominent rocky knob at top of hill north of the Midnight tunnel, about sec. 30, T. 10 S., R. 84 W. (possibly in sec. 25, T. 10 S., R. 85 W.), Pitkin County, Colorado.

Measured by: J. H. Johnson
E. H. Stevens

Bed No.	Description	Thickness (feet)
	Leadville limestone (Mississippian)	
	Top of hill and practically top of formation.	
52	Limestone, dark gray, contains numerous fragments of crinoid stems and much organic debris, some horn corals, suggestions of algal growths; medium bedded; gastropods and *Syringopora* present.....	6.0
51	Limestone, blue-gray, massive (massive layer just under top); some crinoid stems and organic debris.....	11.4
50	Dolomite, upper surface very irregular with a relief of 4 to 5 inches; lower surface fairly regular.....	1.7
49	Limestone, massive, dark.....	10.6
48	Dolomite, brown when weathered, gray when fresh.....	1.9
47	Limestone, very massive, dark gray; crinoid stems, corals.....	15.3
46	Dolomite, brownish, lenses out to east and west.....	1.4
45	Limestone, dark gray, massive, contains much organic material.....	15.4
44	Dolomitic limestone, brownish, thin-bedded.....	4.2
43	Limestone, dark gray, massively bedded; practically a foraminiferal-algal limestone with horn corals.....	4.5
42	Dolomite, gray brown weathering brown.....	23.8
41	Limestone, dark gray, much like one above.....	10.9
40	Dolomite, gray brown, thinly bedded.....	14.4
39	Dolomite, dark gray, thinly bedded.....	13.9
38	Dolomite, brown, medium-bedded; irregular channeling at base.....	10.6
37	Dolomite, medium- to thin-bedded; streaks of depositional breccia.....	12.7
36	Sandstone and depositional breccia; dolomite fragments in a sand matrix.	3.2
	Chaffee formation (Upper Devonian)	
35	Dolomite, thin bedded, light brown, gray or tan.....	7.0
34	Depositional breccia; dolomite fragments in a dolomite matrix.....	1.8
33	Dolomite, dark to light gray, thin bedded; many beds finely laminated....	19.4
32	Dolomite, dark gray, beds 6 to 13 inches.....	17.3
31	Dolomite, light gray to yellow, thin-bedded, finely laminated; breaks of green shale.....	13.0
30	Limestone, black; surface weathers into smoothly rounded knobs.....	1.8
29	Dolomite, black, coarsely crystalline at base grading upward into gray finely crystalline dolomite.....	5.0
28	Dolomite, gray with much secondary siderite.....	6.5
27	Dolomite, gray, beds 3 to 7 inches thick.....	9.2

Bed No.	Description	Thickness (feet)
26	Sandy dolomite. (Grades into next lower member.)	1.4
25	Sandstone, coarse-grained, light brown	2.7
24	Dolomitic sandstone (one layer)	1.1
23	Dolomite, sandy, brown, thin-bedded	1.6
22	Dolomite, gray, thin-bedded; bedding surfaces coarsely rippled and pitted	4.3
21	Covered	18.5
20	Calcareous mudstone, grading upward into a massive mudstone	4.7
19	Calcareous mudstone, grading upward into a massive dolomitic mudstone; lower portion light gray to tan with rectangular fracture	4.2
18	Dolomitic mudstone, yellow on weathered surface, very massive, conchoidal fracture	10.1
17	Shale; green; thin mudstones	0.7
16	Dolomitic mudstone, brown, massive. (One layer)	1.2
	All beds below this indicate deposition in very shallow water, with rippled surfaces, coarse edgewise conglomerate, lenticular beds, and so on. This is true until basal sandstone of Chaffee is reached.	
15	Sandy shale; red shale, and thin red sandstones; thin brown sandstone member about middle	3.1
14	Mudstone, massive, yellow, quite dolomitic	2.7
13	Mudstones and sandy shale. Thin-bedded mudstones, impure dolomites, and green sandy shale; beds very lenticular; beds 1 to 3 inches, rippled, and broken in places into a large-scale edgewise conglomerate	5.6
12	Sandy shale	0.4
11	Sandstone, brown, fine-grained	1.1
10	Brown chert	0.2
9	Sandstones and sandy dolomites, light brown with thin breaks of green shale; layers rippled	6.3
8	Sandstone, brown, medium-grained, coarsely rippled	0.8
	Unconformity. A slightly irregular surface. Channels 4 inches deep and 15 inches wide	
	Manitou dolomite (Lower Ordovician)	
7	Dolomite, thin- to medium-bedded, gray; many dark chert nodules in bands parallel to bedding	9.8
6	Dolomite, gray, finely crystalline, massive to medium-bedded (beds 8 to 15 inches); chert rare; some bedding planes slightly rippled; suggestions of worm trails and borings on and in some layers	18.0
5	Dolomite, dark gray to black; chert practically absent	7.3
4	Dolomite, light gray, beds massive; pronounced bedding plane at top; no chert	12.0
3	Dolomite, beds massive, gray; chert nodules and bands parallel to bedding	21.0
2	Dolomite, gray, medium-bedded; numerous thin bands and stringers of dark chert; bedding planes irregular	19.2
1	Dolomite, light gray, medium-bedded; a few bands and nodules of dark chert	9.6
	Lower beds not exposed:	

Section 9.—ASHCROFT

Measured in first gulch on east side of Castle Creek, north of town of Ashcraft, Colorado. About secs. 23 and 29, T. 11 S., R. 84 W., Pitkin County, Colorado.

Measured by: J. H. Johnson, T. F. Kenney — August 1934

Bed No.	Description	Thickness (feet)
	Chaffee formation (Devonian)	
	Covered, talus, trees and valley bottom.	
30	Gray dolomite beds, 1 to 2 feet thick	21.0
29	Limestones, gray, dolomitic, slightly sandy at base; beds 8 to 15 inches thick; contains small fragments of crinoid stems	32.6
28	Sandstone, brown, cross-bedded; porous texture	3.7
27	Dolomite, light gray, sandy	2.4
26	Sandstone, brown and brown gray	12.6
25	Covered	5.8
24	Mudstones, light yellow and yellow-green	22.4
23	Covered. Float suggests yellow-green mudstones and green sandy shales	15.2

Bed No.	Description	Thickness (feet)
22	Sandstone, red and purplish brown	2.4
21	Sandstone, thinly bedded, light brown; green shales and sandy shales; many layers finely rippled; casts of large halite crystals on some shales	8.6
20	Sandstone, light brown; upper surface coarsely rippled	1.4
19	Sandstone, light yellow brown, and yellow green sandy shales; thinly bedded; some layers quite micaceous	11.8
18	Brown sandstone	2.5
	Unconformity	
	Manitou dolomite (Lower Ordovician)	
17	Dolomite, light yellow gray weathering brown; beds 3 inches to 2 feet thick; a few streaks and nodules of light gray chert	273.0
16	Dolomites, light brown and gray; beds 6 inches to 1½ feet thick; thin breaks of black shale between layers	40.8
15	Black shale; a few carbon impressions of graptolites	0.6
14	Dolomites, light brown; beds 4 to 12 inches thick; surfaces irregularly rippled; abundant fucoid casts	9.4
13	Dolomites and sandy dolomites, thinly bedded; light yellow gray, weathering brown; some black shale breaks; black shales micaceous; abundant worm trails and small fucoid marks	27.0
12	Dolomite, light yellow gray, weathers brown; some layers quite sandy; thin coatings of black shale on bedding planes; streaks of sand in beds; some layers show strong cross-bedding; beds 10 inches to 2 feet	19.5
	Sawatch quartzite (Upper Cambrian)	
	Peerless shale member (?)	
11	Sandstones, brown, some beds slightly calcareous; streaks of sandy limestone	32.0
10	Shale, green, sandy	0.3
9	Limestone, light brown, sandy; depositional breccia	2.6
8	Sandy shale, light olive green, contains worm borings and fucoid casts	5.8
7	Fine-grained sandstone. Some calcareous sandstones interbedded with sandy and calcareous shales. Sandstones brown; shales brown, gray, and green. Most sandstones are edgewise conglomerates; some have "red cast" markings; ripple marks and fucoid casts on some surfaces. A few small black brachiopods in upper shales. Some shales show faint carbon markings suggesting impressions of seaweeds	19.4
6	Sandy shale, green gray, calcareous	1.3
5	Sandstone, light brown, fine-grained, thinly bedded; some layers quite calcareous	7.4
	Sawatch quartzite (Upper Cambrian)	
	Quartzite member	
4	Brown quartzite with bands of white and light-gray quartzite; some cross-bedding; many fucoid marks and rippled surfaces	81.0
3	White quartzite; beds 8 inches to 2 feet thick, partly covered	63.0
2	Conglomeratic sandstone, white, light brown, and red brown; contains numerous well-rounded quartz pebbles up to ½ inch; beds 6 to 15 inches; some layers quite arkosic	15.6
1	Arkosic conglomerate. Pebbles of white quartz up to 1½ inches, average ½ inch; pebbles not thoroughly rounded; mica and feldspar fragments in groundmass; beds 8 to 12 inches thick; shows cross-bedding	8.0
	Unconformity	
	Sawatch-pre-Cambrian contact Surface slightly wavy.	
	Pre-Cambrian Yellow granite, mica schist, and gneiss. Granite rather fine-grained.	

Section 10.—Taylor Pass

Measured along sharp divide between two southern branches of Express Creek about 1½ miles west of Taylor Lake, probably in sec. 9, T. 12 S., R. 84 W.

Measured by: J. H. Johnson — July 8, 1934
T. F. Kenney — August 10, 1934
B. O. Prescott

Bed No.	Description	Thickness (feet)
	Chaffee formation (Devonian)	
	Fault, cuts out top of Chaffee. At least 65 feet more shown in adjoining fault block.	
55	Dolomitic limestones, gray, which weather to a light yellow-gray; thinly bedded	44.0
54	Limestone, dark gray; contains numerous large grains of clear quartz in lower 1½ feet	3.8
53	Sandstone, brown, medium to coarse grains; beds 8 inches to 2 feet thick	18.0
52	Sandstone, yellow; coarse grains of clear quartz in a fine groundmass, suggestions of limonite replacements of large fish plates	4.3
51	Sandy shale, dark gray to black; contains a few quartz pebbles up to ⅜ inch and streaks of yellow dolomitic sandstone	2.0
50	Sandstone, dark brown, coarse-grained; streaks of small quartz pebbles; some poorly developed cross-bedding	14.0
49	Shale, yellow, calcareous, contains poorly preserved fragments of fish plates.	3.0
48	Mudstones, light yellow, beds lenticular; some beds quite calcareous; bedding massive; conchoidal fracture	12 to 19
47	Shales and sandy shales, red	5.4
46	Dolomitic sandstone, red brown; streak of quartz conglomerate at base (well-rounded pebbles up to ½ inch)	1.2
45	Alternating shales and mudstones, pale yellow, brown, and green; ripple marked	5.4
44	Limestone, light gray	1.3
43	Sandy shale, light green gray, very thinly bedded, rippled; some fucoid casts	1.8
42	Sandstone, brown, ripple-marked	0.3
41	Slabby limestone, light gray	0.5
40	Sandstone, coarse-grained with a calcareous cement, light brown	1.5
	Unconformity	
	Manitou dolomite (Lower Ordovician)	
39	Dolomite, light gray; massive beds 1½ to 4 feet thick; numerous nodules of light-gray chert; streaks of dark-blue chert; bedding planes rippled; some surface depressions filled with hematite; upper foot or 18 inches coarsely crystalline	24.0
38	Dolomitic limestone, light gray, thinly bedded; surfaces rippled; a few streaks of gray chert	18.5
37	Dolomitic limestone, dark gray, thin-bedded and slabby; contains numerous fragments of crinoid stems; weathers to a jagged surface	9.0
36	Dolomites, light gray; beds 6 inches to 3 feet thick; a few thin bands of white or light-gray sandstone; streaks or nodules of light-gray or blue-gray chert	46.0
35	Dolomite, light gray; beds 4 inches to 2 feet thick; surfaces slightly rippled; nodules or streaks of light-gray or black chert; a few fragments of crinoid stems in upper layers	48.0
34	Dolomite, light yellow gray, thin-bedded; a few breaks of black shale; some surfaces rippled; fucoid casts in some surfaces; a few black brachiopods about 10 feet below top and some Lingulas about 4 feet below top	23.0
33	Dolomitic sandstones, coarsely rippled with black shaly breaks; one shale layer contains well-preserved graptolites	16.2
32	Quartzite, gray brown, slightly cross-bedded	1.4
31	Dolomite, light yellow gray weathering brown, slightly sandy; beds 2 to 18 inches thick; some surfaces coarsely rippled	10.6
30	Shale, black, slightly sandy	1.2
29	Sandy dolomites, brown, thin-bedded; some surfaces coarsely ripple-marked, others show casts of fucoids and worm borings; a few thin interbedded fine-grained sandstones; streaks of depositional breccia; surfaces of some layers are dark, suggesting carbonaceous material; some beds finely laminated (15 or 20 to an inch)	25.0
	Sawatch quartzite (Upper Cambrian)	
28	Quartzites, brown, with a few interbedded brown sandy dolomites and dolomitic sandstone	21.0
27	Quartzite, purple black	1.0
26	Dolomites interbedded with green-gray sandy shales, slabby, sandy, somewhat rippled; "red cast" effect; streaks of depositional breccia	12.5

Bed No.	Description	Thickness (feet)
25	Shales, fossiliferous green gray to brown; yield small brachiopods	3.5
24	Limestone, slabby shaly with thin shale breaks, light to dark brown; streaks of depositional breccia	6.0
23	Calcareous shale, greenish brown	0.5
22	Shaly limestone, brown	1.8
21	Calcareous shale, greenish brown	0.8
20	Limestone, slabby, shaly, brown	3.1
19	Calcareous shale, greenish brown; contains some brachiopods and fucoid markings	0.7
18	Shaly limestone, fine-grained, brown, massive	2.2
17	Shaly limestone, greenish brown	1.0
16	Depositional breccia, light brown; small (½ to 1 inch) flat pebbles in a dolomitic groundmass	3.5
15	Sandy dolomite, brown, thinly bedded, some ripple marks	16.8
14	Quartzite, brown	9.0
13	Quartzite, white	1.8
12	Quartzite, brown	3.2
11	Quartzite, white	13.7
10	Sandstone, brown	1.1
9	Quartzite, white	5.2
8	Sandstone, brown, porous, probably slightly calcareous	4.4
7	Quartzite, white	2.3
6	Sandstone, brown, slightly calcareous	1.2
5	Quartzite, white	14.0
4	Sandstone, brown, coarse-grained	1.5
3	Quartzite, white, coarse-grained; beds 8 inches to 2 feet thick	27.0
2	Coarse sandstone, white, weathering brown, massive, coarsely cross-bedded, conglomeratic; streaks of pebbles up to 2 inches	19.0
1	Sandstone, light gray, coarse, micaceous; contains quartz pebbles up to 4 inches across	0–0.8

Unconformity

Pre-Cambrian. Upper surface slightly irregular. Upper foot or 15 inches of pre-Cambrian badly weathered. Above several inches of disintegrated granite are practically unworked, then above that several inches of slightly reworked fragments, which grade upward into definitely stratified material.

Notes on Taylor Pass Section

The Sawatch is quite thin. The lower part appears to be absent, apparently as a result of nondeposition and overlap.

No evidence of depositional break could be found between the Sawatch and Manitou. The boundary was drawn arbitrarily so as to agree lithologically as nearly as possible with other sections studied.

The lower Manitou contains an unusual development of black shale beds between the dolomite beds.

No suggestion of the Harding sandstone could be found, and no evidence of Fremont. A dark, rough-weathering limestone occurs about 40 feet below the base of the Devonian, which suggests Fremont lithology, but there were no traces of any of the corals usually abundant in the Fremont.

Section 11.—Mount Tilton (Upper Taylor River)

On the northeast side of Mt. Tilton, Gunnison County, Colorado, in secs. 22, 27, T. 12 S., R. 84 W.

Measured by: J. H. Johnson, B. O. Prescott — June 29, 1934

Bed No.	Description	Thickness (feet)
	Weber (?) formation (Pennsylvanian)	
	Present erosion surface. Not at top of formation.	
48	Shale, black, carbonaceous; alternating limestones and shales, limestones more important upward	27.0
47	Sandstones, conglomeratic, dark gray; contain quartz pebbles up to ¼ inch across	1.3
	Leadville limestone (Mississippian)	
46	Limestone, dark gray and blue gray; very massive beds; a few nodules and streaks of blue chert; upper 5 to 8 feet stained, weathered, and recrystallized	78.0

Bed No.	Description	Thickness (feet)
45	Sandy limestone, dark gray	3.2
44	Limestone, blue	7.0
43	Depositional breccia; grey limestone and dolomite pieces in yellowish sandy matrix	0.8
42	Sandstone, yellow brown; iron stains	3.4
	Chaffee formation (Devonian)	
41	Limestones and dolomitic limestones, gray to dark gray; beds from 1 to 2 feet thick; some depositional breccia	23.0
40	Dolomites and dolomitic limestones, dark gray, massively bedded	65.0
39	Dolomitic limestones, dark gray; react slightly with hydrochloric acid; slabby; contains abundant fragments of crinoid stems, Bryozoa, and brachiopods	11.0
38	Dolomite, dark gray; contains numerous large quartz grains, up to $\frac{3}{8}$ inch.	1.2
37	Yellow clayey limestones and mudstones alternating with greenish shales.	23.0
36	Sandy shales, red and green	3.8
35	Yellow clayey limestones	4.2
34	Sandy shales, red to pink	3.5
33	Dolomites, sandstones, and sandy dolomites, light yellow and brown (sandstones usually light brown); thinly bedded; pronounced edgewise conglomerate at top	8.0
32	Dolomites, sandy, slabby, light yellow, thin (1 to 3 inches), ripple-marked and sun-cracked; casts of small cubic crystals on layer near base	2.5
31	Coarse sandstone; contains a few quartz pebbles (up to $\frac{3}{8}$ inch); streaks of yellowish dolomite	1.5
30	Depositional breccia; fragments of dark dolomite in sandy matrix	0.8
	Fremont limestone (Upper Ordovician)	
29	Dolomitic limestone, dark gray, weathers to a jagged surface; fragments of crinoid stems, abundant traces of corals	13.0
28	Depositional breccia, sandy	$1\frac{1}{2}$ to 5
	Manitou dolomite (Lower Ordovician)	
27	Dolomite, dark gray, massively bedded; streaks and seams of dark gray chert	52.0
26	Dolomite, gray, with thin streaks of gray chert	35.0
25	Dolomites, light gray; beds 1 to $2\frac{1}{2}$ feet thick; cherts sparse at base, becoming more abundant above. Cherts show as silicified fragments of fossils, as thin oval and tubular deposits, and as streaks and large nodules above. Small fragments of crinoid stems in some beds. Cherts white to light gray	53.0
24	Dolomite, yellow gray when fresh, Gray to dark gray on weathered surfaces; Beds 6 inches to $2\frac{1}{2}$ feet thick, average about 15 inches; bedding planes irregular suggesting poorly developed, irregular ripples; some layers slightly sandy; shale between some layers	37.0
23	Dolomite, light gray; beds about 10 inches thick	14.0
22	Sandy dolomites like beds below but the bedding is more massive (average 10 inches to 1 foot)	33.0
21	Slightly sandy dolomite, dark to light brown; beds 3 inches to 1 foot. Average 6 inches; bedding planes irregularly rippled, with worm borings, tracks, and fucoid markings; surface commonly stained with iron or manganese oxides	28.0
20	Dolomite, slightly sandy, light brown; beds 6 to 10 inches thick	21.0
	Sawatch quartzite (Upper Cambrian)	
19	Sandy siltstone, greenish gray to blue gray, slightly micaceous, thinly bedded ($\frac{1}{2}$ to 2 inches); some surfaces strongly ripple-marked	3.6
18	Sandy dolomite, light brown, ripple-marked, glauconitic on bedding planes; contains small fragments of brachiopod shells	6.0
17	Calcareous shale, sandy, blue gray, highly rippled, fucoid marks; traces of trilobite spines	4.7
16	Calcareous sandstone, brown	2.8
15	Calcareous sandstone, shaly, fine-grained; beds $\frac{1}{2}$ to 2 inches thick; contains numerous small flakes of mica; Ripple marked, 3-inch ripples	5.3
14	Massive sandy dolomite and dolomitic sandstone, light gray brown	6.0
13	Dolomites, sandy and shaly, thinly bedded with breaks of greenish-brown shale and calcareous shale	11.0

Bed No.	Description	Thickness (feet)
12	Sandy dolomite, light gray brown, thinly bedded; surfaces coated with iron and manganese oxide stains; fucoid markings and suggestions of trilobite spines	13.0
11	Dolomitic sandstone, brown iron-stained; rather porous; worm borings	5.8
10	Quartzite, white to light brown; dolomitic streaks between upper layers; beds 1½ to 2 feet thick; surfaces coarsely rippled	8.0
9	Quartzite, white to light brown, mottled with dark-brown dolomitic masses; suggests an altered depositional conglomerate	1.3
8	Dolomitic sandstones, dark brown	2.8
7	Quartzite, white	3.5
6	Sandy dolomite, light brown	0.2
5	Quartzite, white to light brown; usually fine, but with streaks of coarse grains or small quartz pebbles; massively bedded (average about 2 feet); some bedding planes show coarse ripple marks	21.0
4	Quartzite, dark gray	3.2
3	Conglomerate, gray brown; white quartz pebbles up to 1 inch across, in a sandy dolomitic matrix	2.4
2	Quartzite, light gray to brown gray; stains dark brown on weathering; beds 10 inches to 2½ feet thick; some layers show pronounced cross-bedding	8.0
1	Quartzite, white; rather fine-grained with streaks of coarse grains; beds 8 inches to 2 feet thick.	
	Fault	
	Some basal beds probably cut out by faulting. Fault brings the Chaffee against the Sawatch.	

Section 12.—North Italian Mountain

Sec. 3, T. 13 S., R. 84 W. Gunnison County, Colo.

Measured by C. H. Behre August, 1931

Bed No.	Description	Thickness (feet)
	Leadville limestone	
25	Dolomitic limestone, light gray to slate gray, with numerous calcite grains, massively bedded	13.2
24	Limestone, banded blue gray with one sooty layer	17.5
23	Limestone, massive, blue gray	22.0
22	Limestone, thin-bedded, shaly	17.5
21	Sandstone, buff, calcareous	22.0
20	Limestone conglomerate	5.5
	Chaffee formation	
	Dyer dolomite member	
19	Dolomitic limestone, weathering light gray	35.0
	Parting member	
18	Quartzite, massive, pinkish, with calcareous cement; weathers pinkish brown	3.25
17	Quartzite, pinkish buff, weathering gritty; in beds 1 foot or less thick	19.5
16	Limestone, flesh-colored, buff-weathering, shaly	11.0
15	Shales, reddish, easily weathering	11.0
14	Limestone, buff, buff-weathering; in beds 1 foot thick	17.5
13	Limestone, massive, pinkish, in beds 3 feet thick; weathering light buff with many maroon surfaces; includes one 2-foot quartzite layer	22.0
12	Shales, mottled reddish and buff sandstone	17.5
11	Shales, yellowish gray, thin, calcareous, impure; faint traces of fossils	22.0
	Top of Manitou dolomite	
10	Limestone, sandy gray to blue gray, massive, dolomitic, beds 3 to 4 feet thick; texture dense to sugary with traces of crinoid stems and weathered-out siliceous fossils; traces of fossils abundant in certain dark beds	170.0
9	Limestone, dolomitic, buff, 2- to 3-foot beds with white chert lenses alternating with dark-gray chert lenses	103.0
8	Dolomite, weathering mottled with siliceous ribbing; rare dark chert lenses	55.0
7	Limestone, weathering pink, slightly sandy, thinly bedded	18.0

Bed No.	Description	Thickness (feet)
	Top of Cambrian	
6	Quartzite, white, pink-weathering	11.0
5	Sandstone, calcareous with maroon partings; beds average 2 feet thick	42.0
4	Pinkish quartzite, buff-weathering limy beds, and thin slabby greenish-gray shales with red cast; 8 inches of purplish beds near top	66.0
3	Quartzite, white, pink-weathering; transition shales	33.0
2	Alternate quartzite layers and sandy beds 2 to 3 feet thick; calcareous cement	28.0
1	Coarse grits and sandy layers alternating	93.0
	Pre-Cambrian	

Section 13.—DEADMAN'S CREEK

Sec. 14, T. 14 S., R. 84 W., Gunnison County, Colorado.

Beds from top of the Sawatch to top of Leadville were measured on north side of valley opposite mouth of fork leading up to Cement Mountain; the Sawatch was measured ¼ to ½ mile farther east.

Measured by: J. Harlan Johnson
Tom Kenney

August 1934

Bed No.	Description	Thickness (feet)
	Gentle grassy slope, probably Weber (?) formation	
	Leadville limestone (Mississippian)	
51	Limestone, blue gray, massively bedded; a cliff-maker	80.0
50	Muddy limestone with streaks of sand and limestone fragments	2.8
49	Depositional breccia; rounded and angular pieces of limestone in brown sand; small quartz pebbles	4.2
48	Brown sandstone	2.3
	Unconformity	
	Chaffee formation (Devonian)	
47	Dolomites, gray to dark gray; some nodules of light blue-gray chert; rather thinly bedded	39.0
46	Dolomites and dolomitic limestone, light gray to gray; thin-to medium-bedding	43.0
45	Limestone, brownish gray, sandy, slabby; contains abundant poorly preserved marine fossils, including very large brachiopods	14.0
44	Sandstone, brown, massive, highly cross-bedded; some layers rather porous	10.3
43	Limestone, light gray	0.5
42	Shale, greenish gray	0.8
41	Limestone, gray; beds 6 to 10 inches thick; surfaces coarsely rippled	9.3
40	Shale, light green	1.7
39	Muddy limestone, light gray; weathers pale yellow, massively bedded	7.4
38	Shale and mudstones, green	7.8
37	Mudstones, yellow	2.0
36	Shale, green	1.1
35	Mudstones, yellow, calcareous	5.8
34	Shale, green, sandy	0.7
33	Mudstone, pale yellow; conchoidal fracture; massive beds	6.2
32	Calcareous mudstone, green gray	1.4
31	Yellow mudstones, massive beds	5.2
30	Slate and mudstones, light green and yellow green, thinly bedded	3.6
29	Dolomitic sandstones and sandstone, thinly bedded; contains abundant fragments of fish plates, spines, and teeth	1.8
28	Sandstones, shales, mudstones, and sandy dolomites, thinly bedded, pale yellow, and soft	11.6
27	Sandstone and sandy dolomites, yellow, fine-grained, thinly bedded; some layers covered with beautiful ripple marks	5.6
26	Shale, light yellow brown, sandy; top carries casts of cubic crystals	0.4
25	Sandstone, light brown, coarse-grained	0.5

Bed No.	Description	Thickness (feet)
	Unconformity	
	Fremont limestone (Upper Ordovician)	
	Top of limestone stained, pitted, and recrystallized.	
24	Dolomitic limestones, dark gray, very massively bedded; contains abundant fragments of crinoid stems, some chain corals and *Receptaculites*.....	52.0
23	Dolomitic limestone, dark gray; beds 18 inches to 2 feet thick; contains abundant fragments of crinoid stems and pieces of shells and corals; bedding planes coarsely rippled (7 to 10 inches).....	12.7
22	Purplish red sandy shale.....	0.3
	Unconformity	
	Manitou dolomite (Lower Ordovician)	
	Unconformity rests on a layer of recrystallized, weathered dolomite, whose upper surface is coated thickly with limonite.	
21	Dolomite, light gray; beds 8 inches to 2 feet; Chert practically absent.....	38.0
20	Dolomites, light gray; beds 4 to 18 inches; a few rounded nodules of white chert.....	12.8
19	Dolomite, light gray; beds 2 to 4 inches; abundant bands and streaks of white chert make up about one-third of the rock.....	2.3
18	Dolomite, light yellow gray; some beds slightly sandy; a few nodules and streaks of white or light-gray chert; beds 7 inches to 2 feet thick.....	51.0
17	Dolomite, light yellow gray with thin layers and streaks of coarse-grained sandstone up to 10 inches thick; sandstone shows strong cross-bedding; beds 2 to 14 inches thick; surfaces rippled, some show abundant fucoid marks.....	10.4
16	Dolomites, light yellow gray; beds 8 inches to 2 feet thick; thin bands, nodules, and streaks of dark-gray chert arranged parallel to bedding.....	31.0
15	Dolomites with nodules and bands of light-gray chert; light-gray beds 8 inches to 2 feet thick.....	38.0
14	Dolomite, yellow gray to light gray, thinly bedded; beds 4 inches to 1½ feet thick.....	23.0
13	Sandy dolomite, fine-grained, brown, thinly bedded.....	11.6
	Sawatch quartzite (Upper Cambrian)	
12	Sandstone, brown, fine-grained, with thin breaks of green shale.....	2.3
11	Sandstone, light brown, cross-bedded.....	3.8
10	White quartzites, massive beds.....	23.0
9	Quartzite, brown and white, massive; some gentle cross-bedding.....	18.7
8	Sandstone and quartzites, red brown; some weather purple and dark brown; massively bedded, strong cross-bedding in some layers.....	11.4
7	Brown sandstone, beds 2 to 14 inches; some layers slightly calcareous; a few thin breaks of shale between sandstones; worm borings; streaks of green sand; beds massive above becoming thinner below.....	51.0
6	Sandstone and limy sandstone, thinly bedded, brown; ripple marks and fucoids on bedding planes; some greensand.....	4.7
5	Sandstone, dark brown.....	
4	Slabby calcareous shale and thin shaly brown sandstone.....	12.9
3	Sandstone, massive, brown.....	10.2
2	Quartzite, white.....	108.0
1	Quartzite, white, conglomeratic with well-rounded quartz pebbles averaging about 1½ inches; lower layer quite arkosic.....	12.0
	Unconformity	
	Pre-Cambrian	
	Quartz-mica schist.....	

Section 14.—CEMENT CREEK

In sec. 18, T. 14 S., R. 84 W., Crested Butte quadrangle.

Measured by: J. H. Johnson
B. O. Prescott

July 7, 1934

Weber (?) *formation* (Pennsylvanian)
Shale, gray.

Bed No.	Description	Thickness (feet)
	Unconformity	
	Leadville limestone (Mississippian)	
52	Covered	90.0
51	Limestones, dark gray	52.0
50	Limestone, gray, with streaks and beds of depositional breccia; blue-gray chert pieces	11.0
49	Depositional breccia; sandstone pieces in a sandy limestone groundmass	4.2
48	Sandstone, light brown to red brown; pieces of gray limestone up to 5 inches thick and 1 foot long imbedded in it; coarse sand grains	2.6
	Unconformity	
	Chaffee formation (Devonian)	
47	Limestone, dark gray, slightly dolomitic	37.0
46	Limestone and dolomitic limestone, light gray, weathers buckskin color; beds 6 inches to a foot thick; nodules of light blue-gray chert	11.0
45	Limestone, light gray; streaks and beds of depositional breccia; beds 3 to 7 inches thick	5.1
44	Sandy depositional breccia; limestone pieces in a fine sand cement	4.2
43	Sandstone, light to dark brown, hard	7.5
42	Quartzite, white	1.4
41	Shale and soft sandstone, green and purple	0.8
40	Dolomitic limestone, light to dark gray; beds 6 inches to 1 foot thick; a few nodules of light-gray chert	16.5
39	Sandy limestone, light gray to tan, massively bedded but finely laminated on weathered surfaces	11.0
38	Dolomitic limestone, light gray; beds 4 inches to 1 foot thick; weathers nodular; streaks of fine depositional breccia near top	9.6
37	Sandy limestone and limy sandstone, dark gray; contains marine fossils	8.3
36	Limestone, dark gray, massively bedded but weathers into rough slabs, fossiliferous	22.0
35	Sandy limestone, gray	1.8
34	Sandstone, yellow gray, weathering dark brown and red brown; massive cross-bedding in upper two-thirds; rather porous weathered surfaces	16.0
33	Calcareous sandstone, green	2.8
32	Muddy limestone, pale yellow to yellow green, massively bedded; calcareous shale breaks; beds 3 to 5 feet thick	17.0
31	Muddy limestone, sandy and calcareous shales; pale yellow and green, rather thinly bedded	12.0
30	Sandstones, sandy shales, and calcareous mudstones; pale yellow, green, red, and purplish; thinly bedded	7.8
29	Sandstones and sandy shales, light greenish gray or yellowish, thin, somewhat micaceous, highly ripple-marked (ripples 2 to 8 inches); one layer has casts of small cubic crystals	17.3
28	Sandstone, light yellow	2.0
27	Sandstones and shales, light gray, soft	1.5
	Unconformity	
	Fremont limestone (Upper Ordovician)	
26	Dolomite, dark gray, massive; fragments of crinoid stems abundant; chain corals and *Receptaculites* observed	39.0
25	Depositional breccia; Limestone pieces in a sandstone matrix	1.4
	Unconformity	
	Manitou dolomite (Lower Ordovician)	
24	Dolomite, cream to dark-gray; massive beds 10 inches to 2½ feet thick; a few streaks and nodules of white or light-gray chert	57.0
23	Dolomite, cream-colored; beds 8 inches to 2 feet thick; thin green sandy breaks between beds; some silicified shell fragments and a few nodular masses of white chert	71.0
22	Dolomite, cream to light brown; beds 3 inches to 1 foot; many bedding planes show poor ripple marks; thin breaks of fine greensand between some layers; trace of silicified shell fragments in upper layers	46.0
21	Dolomite, thinly bedded; some layers quite sandy; beds 2 to 6 inches thick; very thin breaks of pale-green shale or sandy shale between layers; fucoid marks	6.3
20	Sandy dolomite, light tan	2.2

Bed No.	Description	Thickness (feet)
	Sawatch quartzite (Upper Cambrian)	
19	Quartzite, white, massively bedded	28.0
18	Sandstone, tan to pale green, light brown on weathered surfaces, slightly cross-bedded; beds 1 foot to 18 inches thick	12.6
17	Sandstone, pale green to white, soft with calcareous cement, massive, riddled with worm borings	12.5
16	Depositional breccia. Flat pieces of sandstone and limestone in a fine sandstone matrix	2.3
15	Sandstone and quartzite, brown, cross-bedded; massive beds with a few thin calcareous streaks and bands	21.7
14	Sandstone, greenish and yellow gray, very fine-grained, soft, thin-bedded	2.8
13	Calcareous sandstone alternating with a sandy dolomite, light tan to dark brown; lenses and bands of a fine depositional breccia	17.0
12	Sandstones with thin calcareous bands, green to dark brown, massively bedded; much fine cross-bedding; greensand abundant	37.0
11	Limestones, sandy limestones, and calcareous sandstones, light brown with thin breaks of green sandy shale between layers; beds 6 to 15 inches thick; surfaces coarsely ripple-marked; some bedding planes covered with large fucoid casts; some layers contained thin bands of green sandstone; layers of depositional breccia near top	8.2
10	Sandstone, brown, thinly bedded, slabby with shale breaks; surfaces rippled; some fucoid markings	1.6
9	Sandy limestone; upper half depositional breccia	1.8
8	Calcareous shale, green	1.2
7	Sandstone, brown	1.0
6	Calcareous sandy shale, green	0.8
5	Sandstone, brown gray with breaks of greenish shale, soft; streaks of green sand containing worm borings	24.0
4	Quartzite, white, medium-to fine-grained; beds 6 to 18 inches thick	19.0
3	Sandstone, white to light gray, slightly pinkish on weathering, coarse-grained, sugary; contains occasional quartz pebbles up to 1 inch	15.0
2	Quartzite, white, cross-bedded, fine-grained; beds 6 inches to 2 feet	12.0
1	Covered with talus	45.0
	Unconformity	
	Pre-Cambrian	

Section 15.—Cement Creek No. 2

Measured along gulch on north side of Cement Creek 0.4 miles above Cement Creek Ranger station in sec. 14, T. 14 S., R. 85 W., Gunnison County, Colorado.

Measured by: J. H. Johnson, T. F. Kenney — August 13, 1934

Bed No.	Description	Thickness (feet)
	Weber (?) *formation* (Pennsylvanian) shale and shaly limestone, black.	
	Leadville limestone (Mississippian)	
59	Limestone, gray	1.7
58	Pisolitic limestone, dark gray to black; suggests algal limestone	2.6
57	Limestone, dark gray, massively bedded; a cliff maker; contains fragments of crinoid stems	38.0
56	Limestone, dark gray, massively bedded; contains scattered crinoid stems corals, and large gastropods	32.0
55	Limestone depositional breccia, some sand	1.3
54	Sandstone with streaks of fine quartz conglomerate at the base, brown	5.2
	Chaffee formation (Devonian) (Boundary not certain)	
53	Covered	6.3
52	Dolomite, sandy in places, light brown, thinly bedded; fragments of crinoid stems and *Syringopora* corals and cup corals	22.0
51	Dolomitic limestone, dark gray; contains fragments of corals, crinoid stems, and brachiopods; beds 1½ to 4 feet thick	31.0
50	Dolomite, light gray; beds massive	35.0
49	Dolomitic limestone, dark gray; beds massive	7.0
48	Dolomite, dark gray; thin bands of depositional breccia; partly covered	49.7

Bed No.	Description	Thickness (feet)
47	Dolomitic limestone, light gray; beds six inches to 1 foot	10.8
46	Dolomitic limestone, dark gray; beds 4 inches to 1 foot	15.0
45	Limestone, light gray, thinly bedded	19.2
44	Limestone, dark gray, thinly bedded, laminated; thin layers of limestone depositional breccia	8.3
43	Sandy shale and calcareous sandstone, purple gray and green gray; abundant worm borings	2.8
42	Sandstone, white to light brown, sugary, massive; suggestion of cross-bedding	19.2
41	Limestone, very light gray, weathering yellowish; beds 8 inches to 1½ feet thick; contains a few tabular concretions of greenish-white chert, which suggests fucoid casts; streaks of depositional breccia; some layers almost chalky	39.8
40	Slabby limestone, white; marine fossils	34.6
39	Slabby limestone, yellow, light gray, and pink; fragments of marine fossils	10.2
38	Limestone, purplish, thinly bedded; some layers crinoidal and carry Bryozoa and brachiopods	4.8
37	Sandy dolomites, sandstones, and dolomitic sandstones, light yellow to brown, slightly cross-bedded; beds average about 1 foot thick	13.6
36	Soft shales, mudstones, and calcareous mudstones, pale yellow and green	7.5
35	Shale, green gray	1.4
34	Mudstones, light yellow and yellow green; massive beds	18.7
33	Mudstones, shales, and limestones, light yellow and gray, thinly bedded	9.2
32	Mudstone, light yellow	1.2
31	Sandstone and shale, sandy shale, and mudstones, red, light green, gray, and yellow mottled, thinly bedded, slightly micaceous	10.6
30	Sandstone, light gray, alternating with sandy limestone; thinly bedded, ripple-marked (ripples 3 to 5 inches, trend SE to NW along ridges); thin layer with casts of cubic crystals on top (as large as 1½ inches on side); streaks of limestone conglomerate	5.4
29	Sandstone, gray-brown, cross-bedded; beds 2 to 6 inches thick and coarsely rippled	2.3
	Contact Chaffee-Fremont Contact slightly wavy.	
	Fremont limestone (Upper Ordovician)	
28	Limestone, gray, massive; beds 1.8 to 5 feet thick; abundant fragments of crinoid stems and corals; top stained and recrystallized	38.0
	Harding sandstone (Middle Ordovician)	
27	Muddy and sandy limestone, white, pale green, and pinkish, massively bedded; contains abundant fragments of crinoid stems and fish plates	5.6
26	Sandstone, white with purplish black streaks and bands; top purplish and full of fish plates	5.7
25	Quartzite, purplish gray; contains fragments of small fish plates, streaks of green sand	0.8
	Unconformity	
	Contact Harding-Manitou	
	Manitou dolomite (Lower Ordovician)	
24	Dolomite, gray, massively bedded; top badly stained and recrystallized	17.0
23	Dolomite, white to yellow gray; beds 6 to 18 inches thick; chert practically absent; cliff-maker	53.0
22	Dolomites, white to pale yellow gray; abundant streaks and nodules of white chert; thinly bedded with breaks of green shale; ripple marks	28.0
21	Dolomites, white to light yellow gray; beds 4 inches to 2 feet; contain abundant streaks, nodules, and bands of white chert; some surfaces show ripples and coarse fucoid casts; abundant crinoid stems in upper layer	25.3
20	Dolomites, like those below only more massively bedded; contain a few small nodules and thin streaks of white chert, Crinoid stems and Lingulas	21.0
19	Dolomites, light yellow gray, some almost white; some layers slightly sandy; beds 2 to 10 inches	25.5
18	Sandy dolomite, layers of dolomitic sandstone; beds 1½ to 6 inches	6.4
17	Dolomitic sandstone, light brown; coarse quartz grains in a dolomitic groundmass	1.8

Unconformity

Bed No.	Description	Thickness (feet)
	Sawatch quartzite (Upper Cambrian)	
16	Quartzite, white	1.8–3.2
15	Sandstone, white to cream, weathering brown to black, fine-grained; massively bedded, 1 to 5 feet; cross-bedding in some layers	33.0
14	Sandstone, light pink to tan, find grained; some layers slightly calcareous; massively bedded, 10 inches to 3 feet thick; thin breaks of green shale	10.8
13	Sandstone, white to pink, weathering red and brown, massive, cross-bedded	17.0
12	Sandstone, pink and tan, thinly-bedded; some layers slightly calcareous	11.0
11	Sandstone, massive, red brown, alternating with thinly bedded green sandstone and sandy shale. Sandstones contain streaks and bands of greensand (glauconite?). Worm borings, trails, and fucoid casts and markings abundant	52.5
10	Sandstone, green, gray and brown, thinly bedded	40.8
9	Sandstone, red and brown, with streaks and thin bands and patches of greensand; beds 4 to 16 inches thick; ripple marks, worm tracks, and fucoid casts on bedding planes	13.0
8	Slabby sandstones, calcareous sandstones, and sandy limestones, thinly bedded, pink to white; some beds finely rippled; upper layers contain streaks and patches of greensand	13.5
7	Quartzite, red brown, highly cross-bedded	4.0
6	Quartzite, white with red and brown interbedded	17.0
5	Sandstone, red brown, medium-to fine-grained with streaks of coarse grains; beds 4 to 18 inches thick; some poor cross-bedding	26.0
4	Quartzite, white and red brown, weathers light brown; beds 6 inches to 1 foot thick	17.0
3	Quartzite and sandstone, white, sugary, rather coarse-grained; beds 6 inches to 2 feet thick; gentle cross-bedding; some layers contain numerous worm borings	28.4
2	Quartzite, white, coarse-grained; a few streaks of pebbles	9.7
1	Quartz conglomerate, white; pebbles of white quartz up to 3½ inches; lowest bed quite arkosic	4.2
	Pre-Cambrian	
	Granite, pink.	

Section 16.—Cross Mountain

Measured on northeastern side of Cross Mountain in sec. 20, T. 15 S., R. 82 W., Gunnison County, Colorado.

Measured by: J. Harlan Johnson, B. O. Prescott — July 3, 1934

Bed No.	Description	Thickness (feet)
	Porphyry sill at top of peak:	
	Leadville limestone (Mississippian)	
40	Limestone, dark gray	47.0
39	Limestone depositional breccia in a limestone matrix; sand grains	6.2
38	Sandstone and sandy limestone, contains angular and rounded fragments of gray limestone	3.2
	Unconformity	
	Chaffee formation (Devonian)	
37	Dolomitic limestone, dark gray; some beds ripple-marked (10-inch ripples)	32.0
36	Dolomitic limestone, dark gray, massively bedded	37.0
35	Dolomitic limestone, light gray, medium-bedded; abundant small fragments of fossils	19.0
34	Dolomitic limestone, dark gray to yellow gray, massively bedded (1½ to 4 feet)	27.0
33	Sandy limestone, brown; contains large grains of quartz	2.5
32	Sandstone, brown, slightly limy; conglomeratic, with fragments of gray and black dolomite, chert pebbles, and coarse quartz grains, in a fine sand	

Bed No.	Description	Thickness (feet)
	matrix; surface rippled and depressions filled with dark material; some layers show abundant fucoid casts; fish fragments abundant at base	11.0
31	Sandstone, light gray, massive	6.5
30	Dolomitic limestone, light gray	8.4
29	Limestone and muddy limestone, white to pale yellow, massive	11.0
28	Muddy limestone, yellow, massively bedded	7.0
27	Calcareous mudstones, sandy and shaly, greenish yellow	1.3
26	Muddy limestones and limy mudstones, yellow, massively bedded	19.6
25	Alternating red shales and yellow mudstones	3.5
24	Red shales and mudstones	3.0
23	Alternating thin sandstones and sandy calcareous mudstones. One layer shows beautiful casts of cubic crystals. Beautiful ripple marks on bedding planes. Beds ½ to 3 inches thick. Small, poorly preserved fragments of fish plates in lower 5 feet. Green and red shale streaks near top	19.0
22	Sandstone, brown; coarse quartz grains	1.0
21	Sandy shale, yellow	0.4
20	Conglomeratic sandstone with fragments of dark dolomite in yellow sandstone	0–0.5
	Unconformity	
	Fremont limestone (Upper Ordovician)	
	Contact irregular.	
19	Dolomite, dark gray; massive beds; contains crinoid stems and poor chain corals	32.0
	Harding sandstone (Middle Ordovician)	
18	Sandstone, brown to yellow red brown. Cross-bedded, rather porous. Fish plates, present, abundant near top; preservation is limonitic and poor	5.0
	Unconformity	
	Manitou dolomite (Lower Ordovician)	
17	Dolomite, light gray	14.0
16	Dolomite, dark blue gray to almost black, massively bedded; crinoid stems	37.0
15	Dolomite, dark gray, massively bedded; some layers slightly sandy	19.0
14	Dolomite, light to dark blue gray, massively bedded (18 inches to 4 feet); a few streaks and nodules of white or light-gray chert; suggestions of fossils	53.0
13	Dolomite, light blue gray; light gray, blue gray, and white chert abundant as streaks, layers, and irregular masses. Chert also occurs as tubular masses on top of bedding planes. In some layers chert forms 50 per cent of mass. Bryozoa and shell fragments in upper layers	34.0
12	Dolomite, light blue gray to yellowish gray; effervesces slightly with HCl; a few streaks and bands of light bluish-gray chert; beds 1 to 2 feet thick, average about 14 inches; a few suggestions of fossils	26.2
11	Dolomite, light brownish gray; beds 4 inches to 1 foot thick; limestone quite sandy	17.0
	Sawatch quartzite (Upper Cambrian)	
10	Quartzite, white, massively bedded (2 to 4 feet); hard, a cliff-maker. Top surface shows abundant worm borings, trails, and so on, and is darkly stained	24.0
9	Sandy solomite, light tan; alternating with a few dolomitic sand-stones; thinly bedded (4 to 10 inches), soft	27.0
8	Dolomitic sandstone, light tan, cross-bedded	3.6
7	Quartzite, dark purplish red, hard, beds 8 inches to 1½ feet; surfaces show ripples, fucoïds, worm trails, and so on; a few thin dolomitic streaks; upper 6 feet shows pronounced cross-bedding	29.5
6	Partly covered. Consists mainly of light-tan sandy dolomite alternating with quartzites	18.+
5	Sandy dolomite, light brown; breaks of shale; suggestions of fucoids	7.0
4	Quartzites, gray and light brown, thin; streaks and thin interbedded layers of sandy dolomites; many worm borings	4.8

Bed No.	Description	Thickness (feet)
3	Quartzites, brown and dark gray; contain many worm borings	13.0
2	Quartzites, white and gray, interbedded	60.0
1	Covered with morainal debris	160.0+

Unconformity

Pre-Cambrian

Section 17.—ROUND MOUNTAIN

On Round Mountain about sec. 28, T. 14 S., R. 81 W., Sixth Principal Meridian, Gunnison County, Colorado.

Measured by: J. Harlan Johnson June 22, 1934

Bed No.	Description	Thickness (feet)
	Top of mountain (erosion surface)	
	Leadville and Chaffee formations (Mississippian and Devonian)	
28	Limestone, very dark gray, massively bedded; contains a few dark-gray chert masses 1 to 4 inches long	63.0
27	Limestone, light gray, massively bedded; numerous beds and streaks of depositional breccia	38.0
26	Limestone, light gray, thinly bedded	15.5
25	Limestone, very thin beds (½ to 2 inches); contains a few shell fragments	6.8
24	Dolomitic limestone (slight acid reaction)	7.5
23	Limestone, black; some depositional breccia	3.8
22	Calcareous mudstone, yellow	2.0
21	Sandy slabby dolomites, light gray to yellow; coarsely ripple-marked (6- to 8-inch ripples)	4.6
20	Dolomite, light and dark gray, thinly bedded	18.0
19	Limestone and breccia, black; pieces of dark chert and gray limestone in a black oölitic matrix	1.0
18	Dolomitic limestone, light gray, thinly bedded	39.0
17	Quartzite, light brown; contains dolomite streaks and grains; some tiny structures suggest silicified algae; a few worm borings	13.0
16	Muddy limestone, light yellow, massively bedded	4.6
15	Calcareous shales and mudstones, yellow and green	5.0
14	Dolomite, light purplish yellow	3.5
13	Dolomites, dolomitic sandstones, mudstones, and shales, yellow, red, light gray, and mottled, thinly bedded; some beds beautifully ripple-marked (1-inch ripples)	25.0
12	Depositional breccia. Dark-gray dolomite fragments in a yellowish sandy dolomite matrix	0.5–1.0
	Fremont limestone (Upper Ordovician)	
11	Dolomite, dark gray, massively bedded; contains abundant crinoid stems	28.0
	Harding sandstone (Middle Ordovician)	
10	Quartzite, white to dark red, and purple; dark layers contain bluish-white quartzite grains up to ¼ inch in size; contains platelike limonite flakes which may be replaced fish plates	7.0
	Manitou dolomite (Lower Ordovician)	
9	Dolomite, gray, massively bedded; contains silicified fragments of crinoid stems and shells	47.0
8	Dolomite, light gray; contains nodules and streaks of chert. Chert varies from almost white to dark gray. Tends to be thin-bedded (4 to 6 inches, a few up to 1 foot)	43.0
7	Dolomite, gray; contains worn fragments of dolomite and large sand grains	2.0
6	Sandy dolomite, light tan	7.0
	Sawatch quartzite (Upper Cambrian)	
5	Quarzite, white, thinly bedded	18.0
4	Sandstone and quartzite, dark red; beds about 1 foot thick; worm borings very abundant	21.0
3	Sandstone and sandy shale, greenish yellow; sandstones slightly glauconitic	16.0

Bed No.	Description	Thickness (feet)
2	Dark quartzite, red brown to gray; contains streaks and bands of dolomite and dolomitic sandstone, calcareous shales near top; poorly preserved impressions of trilobite spines in sandy dolomites; some layers of depositional breccia	45.0
1	Quartzite, white; about a foot of coarse slightly conglomeratic quartzite at base, rest medium- to fine-grained; some beds sugary	41.0
	Pre-Cambrian	
	Mica schist and hornblende schist	

Section 18.—Tincup Section

On hill in sec. 19, T. 15 S. R. 81 W., just north of El Capitan Mine, Tincup district, Gunnison County, Colorado.

Bed No.	Description	Thickness (feet)
	Fault	
	Leadville limestone	
18	Limestone, dark gray	70
17	Limestone, dark gray with depositional breccia	28
16	Sandstone, arkosic	1.5
15	Limestone, dark blue black	16
14	Dolomite, dark gray black, sandy (contains corals)	5
13	Limestone, blue gray (corals of Mississippian age)	11
12	Limestone, blue gray	18
11	Limestone, blue gray, beds 4 to 8 feet thick (fossiliferous)	60
10	Limestone, dark gray; depositional breccia near base	25
	Chaffee formation	
9	Limestone and dolomite, yellowish gray and gray, thin-bedded	50
8	Yellow calcareous mudstones alternating with greenish limy shales	12
7	Limestones and dolomites, slabby, gray and tan, thin-bedded	14
6	Limestones and dolomites, slabby, gray and tan, thin-bedded	14
5	Shales and shaly limestones, sandy and calcareous; green, gray, purple and tan. Casts of salt crystals abundant on layer about 3 feet above base	8.2
4	Conglomeratic sandstone; small quartz pebbles up to ¼ inch and limestone fragments	1.3
	Devonian-Fremont Contact. Unconformity.	
	Freemont limestone	
3	Dolomite, dark gray, weathers to a ragged surface; contains crinoid stems, chain corals, and tiny fragments of shells	38.1
	Unconformity	
	Harding sandstone	
2	Quartzite, purplish, grading upward into a yellowish limy quartzite at top; well-preserved fish plates abundant	10
	Unconformity	
	Manitou dolomite	
1	Dolomites, light yellowish gray, somewhat siliceous	60±
	Porphyry dike	

Section 19.—Fossil Ridge

Measured in and above cirques at head of Boulder Creek in secs. 11, 12, and 14, T. 51 N., R. 3 E., New Mexico Meridian, Gunnison County, Colorado. (Leadville at head of Crystal Creek on west side of Ridge. Pennsylvanian at head of Comanche Creek.

Measured by: J. Harlan Johnson, B. O. Prescott — June 15–20, 1934

Bed No.	Description	Thickness (feet)
	Pennsylvanian sediments	
45	Limestone and shale, alternating; black. Shales form slightly more than half the sequence. Limestones are very dark gray to black, some shaly; beds up to 5½ feet thick averaging about 1 foot; a few fragments of fossils observed. Shales are black, some are quite calcareous; some near base are slightly sandy. Nodules of black chert	192.0

Bed No.	Description	Thickness (feet)
44	Shaly limestone with streaks of oölitic and pisolitic limestones, black	4.0
43	Shale, black; some beds slightly calcareous; a few thin dark-brown sandstones near base	42.0
42	Sandstone, light gray to greenish gray, containing large quartz grains in a fine matrix	36.0
41	Sandstone and sandy shale, red, reddish yellow, and mottled; a few streaks of shaly limestone	11.0
40	Conglomerate composed of semi-angular and well-rounded fragments of black chert, limestone, dolomite, and quartz in a matrix of quartz grains	3.0–5.0
	Leadville limestone (Mississippian)	
39	Limestone, dark blue gray, contains black chert; a thin porous yellowish bed about 10 feet below top	28.0
38	Cherty limestone, brownish or dark gray, thinly bedded; chert locally very abundant	18.0
37	Quartzitic sandstone, white	1.5
36	Cherty limestone, dark blue gray; contains layers of dark gray to black depositional breccia	22.0
35	Quartzite, white, medium- to fine-grained, even-textured	15.0
34	Cherty limestone, blue gray, thinly bedded	75.0
33	Dolomitic limestone, blue gray, massively bedded	48.0
32	Dolomitic limestone, light yellow gray, sandy, rather porous	5.5
31	Limestone, gray, brown, or yellowish brown, locally shaly and clayey; some impure chert	11.0
30	Limestone, blue gray to brown gray, massively bedded	141.0
29	Limestones, gray; contains streaks of depositional breccia; massively bedded at base, beds becoming thinner upward until quite thin near top	150.0
	Chaffee formation (Devonian)	
28	Impure dolomitic limestones, brown to yellow gray, thinly bedded, some beds quite clayey	26.0
27	Dolomite, light gray, hard	23.0
26	Cherty dolomites, dark blue gray; contain streaks of depositional breccia	50.0
25	Calcareous mudstones, yellowish gray to dark gray	14.0
24	Dolomitic limestone, dark gray to black, massive at base, becoming slabby and impure (sandy or shaly) at top; very fossiliferous, but good specimens difficult to obtain; fossils include brachiopods, crinoid stems, Bryozoa, and a few corals	27.0
23	Dolomitic sandstone or sandy dolomite, light yellow to dark brown; usually very porous on weathered outcrops; shows some fine banding and suggestions of cross-bedding	9.0
22	Sandstone, calcareous, grading into sandy limestone, irregularly bedded. Locally concentric cabbagelike structures suggesting algae; abundant fucoid markings on upper surface	4.8
21	Fine-grained calcareous mudstone, a few interbedded sandy clayey dolomites. Light green to yellow tan; streaks of green sandy shale; beds alternately thick and thin; some beds slightly mottled with red and brown	19.0
20	Calcareous mudstone, yellow, massive	4.0
19	Calcareous shale, light green	4.5
18	Limestone, massive, clayey, light yellow; prominent on outcrops	5.5
17	Shales, light yellow, calcareous, and sandy	8.0
16	Calcareous mudstones, red, pink, and green, thinly bedded	13.0
15	Sandy dolomites, yellow buckskin-colored, thinly bedded, highly ripple-marked; sun cracks in some lower beds. (1½- to 4-inch ripples). At base a thin bed is covered with casts of cubic crystals ⅜ to ¾ inch across; suggest salt	18.0
14	Hard sandy dolomite, somewhat conglomeratic at base, containing smooth pebbles of dark limestone (up to 1½ inches) and coarse quartz grains	2.0
13	Sandy dolomite, yellowish with a few fragments of dark-gray dolomitic limestone; contains abundant fragments of fish plates up to 4 inches across, some are well preserved; others are replaced with iron oxide and are poorly preserved	9.0
12	Conglomerate of both angular and rounded pieces of Fremont limestone, quartz sand, and small quartz pebbles, bound together with a calcareous cement; small fragments of fish plates and teeth in conglomerate	0.8–1.5

Unconformity. Slightly irregular surface

Bed No.	Description	Thickness (feet)
	Fremont limestone (Upper Ordovician)	
11	Dolomitic limestone somewhat sandy, dark gray; weathers to a rough jagged surface; massively bedded; topographically a cliff maker; contains abundant crinoid stems, small horn corals, and more rarely chain corals, cystoid plates, and fragments of brachiopod shells. At top a zone 1 to 5 feet thick shows signs of weathering. Some recrystallization.....	35.0–38.0
	Harding sandstone (Middle Ordovician)	
10	Quartzite, white to dark red brown. A few small typical Harding fish plates, and many weathered pieces of limonite, which suggest replaced and altered fish plates.....	4.0
9	Sandy shale, greenish.....	0.2
8	Quartzite, white, with limonite fragments and stains.....	6.0
	Manitou dolomite (Lower Ordovician)	
7	Dolomite, generally light to dark gray, some light red or purplish pink locally on weathered surfaces; massively bedded, beds 8 inches to 4 feet averaging about 14 inches; fine-grained and compact; traces of crinoid stems and silicified fragments of shells. Some layers show a fibrous structure on weathering suggesting algal limestone. Topographically may form low cliffs.....	78.0
6	Dolomites, light gray; some beds pink or greenish on weathered surfaces; beds 4 inches to 2½ feet averaging about 9 inches; contain chert, but much less than beds below.....	60.0
5	Impure siliceous dolomites, some beds quite sandy; sand grains, some large, are scattered through the dolomite; thin breaks of shale, probably more abundant than appear on outcrops. Dolomite is crystalline. Many beds appear quite porous. White to light gray chert is abundant above lowest 15 or 20 feet. Chert occurs as round or oval concretions, streaks, or as branching tubular masses. Latter are best developed along bedding planes. They suggest replaced fucoid casts. Dolomites are thinly bedded (2 inches to 1½-feet, averaging 4 to 6 inches). Many beds show ripple-marked surfaces.....	74.0
	Sawatch quartzite (Upper Cambrian)	
4	Sandstone, locally a quartzite, white to pink, weathering dark gray or brown; beds thick, averaging about 28 inches; worm borings not uncommon; some layers quite sugary.....	30.0
3	Impure quartzite with interbedded thin impure dolomite, usually white or light gray, thinly bedded; at base is a layer of coarse micaceous sandstone that usually weathers to red brown; other beds are rather fine-grained. small nodules of chert are not uncommon. Streaks and irregular lenses of greenish-gray shale.....	47.0
2	Quartzite, white to light gray weathering to red or yellow tints, fine-grained and compact, massively bedded; hardest part of formation usually a cliff maker, and supplies most of talus on slopes.....	40.0
1	White quartzite conglomerate composed of well-rounded pebbles of white quartz, jasper, and quartz up to about 2 inches across in a matrix of white quartz grains.....	1.8

Unconformity. A slightly irregular surface

Pre-Cambrian gneiss and schist

Section 21.—West Fork Express Creek

Devonian and a part of Mississippian rocks on west fork of Express Creek at lower end of cirq
(Just south of fork of creek.) About west side of sec. 9, 12 S., R. 84 W., Pitkin County, Colora

Measured by: J. Harlan Johnson
E. H. Stevens
July 1, 19

Bed No.	Description	Thickness (feet)
	Leadville limestone (Mississippian)	
	Top of measurable section.	
29	Limestone, dark gray, fossiliferous, (USGS Locality 8460). Yielded specimens of *Syringopora surcularia* Girty, *Craninia* sp. undet., and *Neozophrentis?* sp. undet.....	37.0

Bed No.	Description	Thickness (feet)
28	Covered by talus	24.0
27	Dolomite, dark gray, medium to thick beds	55.0
26	Depositional breccia, grades into dolomite above	5.4
25	Sandstone, brown, medium-grained; fragments of chert and dolomite in basal portion. Rests on a channeled surface with channels 2 to 3 feet wide and 3 to 4 inches deep. Small sandstone dikes extend 3 to 5 inches into dolomite beneath	1.4
	Unconformity	
	Chaffee formation (upper Devonian)	
24	Dolomite, gray, beds medium to massive; many show fine banding or laminations; lenses of depositional breccia near base; some small lenses of chert	16.9
23	Depositional breccia. Subangular pieces of dolomite in a sandy dolomite matrix; fragments in breccia up to 5 by 3 inches	3.0
22	Dolomite, gray-weathering, light-gray beds, 10 to 16 inches thick	8.7
21	Dolomite, gray weathering light gray, fine-textured beds 2 to 6 inches thick, slightly laminated	12.4
20	Depositional breccia. Fragments of blue-gray limestone and light-gray dolomite in a matrix of sand and sandy dolomite	2.6
19	Sandstone, brown, coarse-grained, irregularly silicified; massive beds; suggestions of cross-bedding near base; grades upward into depositional breccia	6.8
18	Depositional breccia. Dolomitic ground mass and fragments; grades into bed below	1.1
17	Limestone, blue gray grading upward into a depositional breccia; irregular channeled surface	3.0
16	Dolomite, light gray, weathers a light brown; beds 4 to 12 inches; vugs and fractures contain small crystals of dolomite; upper layers are granular, crystalline	5.5
15	Dolomite, light gray, weathers light tan; beds 2 to 8 inches	16.4
14	Dolomite, bluish gray, weathering light gray	2.1
13	Dolomite, light gray, fine-grained; beds medium to massive; many beds weather to a fine netted or almost fibrous surface pattern; a few nodules of dark-gray chert	33.5
12	Dolomite, light gray weathering tan; massive beds; fine-grained	11.4
11	Dolomite, dark gray; numerous coarse quartz grains at base, becomes less sandy upward; slabby	5.0
10	Sandstone, very coarse-grained, sand grains up to ¼ inch; weathers dark brown; beds massive; strong cross-bedding; some layers almost a quartzite	16.6
9	Dolomite, impure, dark gray, thin-bedded; streaks and breaks of dark-gray sandy shale. (This layer is soft and is covered in most places.)	13.6
8	Sandy dolomite, gray; coarse sand grains in a fine dolomite	4.5
7	Sandstone, brown, coarse-grained, cross-bedded; ridge-maker	7.8
6	Mudstones, dolomitic, thinly bedded with shale breaks; mottled purple	2.9
5	Mudstones, yellow-tan, somewhat dolomitic; massive beds; weather into irregular nodular forms; breaks of green shale between layers	7.2
4	Sandy dolomite, light yellow with purplish-red spots	2.4
3	Mudstones, very fine-grained, slightly dolomitic, greenish yellow when fresh, light yellow on weathered surface; massive beds, hard and dense	4.6
2	Covered. (*See* Taylor Pass section 10 for details.) Apparently soft slabby sandstone and green shale	23.0
1	Sandstone, brown, medium texture; small lenses of dolomitic sandstone at top	1.6
	Unconformity. Surface irregular. Channels 2½ feet wide and 2 to 3 inches deep	
	Manitou dolomite and older beds. (*See* Taylor Pass section 10.) This was measured across cirque about ½ mile to WNW.	

Section 22.—Express Mine

Leadville and upper part of Chaffee formations, just north of old Express Mine on Express Creek, one mile south of Ashcroaft about sec. 32, T. 11 S., R. 84 W., Pitkin County, Colorado.

Measured by: J. H. Johnson — June 30, 1937
E. H. Stevens — July 1, 1937

Unconformity. Slightly irregular surface

Bed No.	Description	Thickness (feet)
	Fremont limestone (Upper Ordovician)	
11	Dolomitic limestone somewhat sandy, dark gray; weathers to a rough jagged surface; massively bedded; topographically a cliff maker; contains abundant crinoid stems, small horn corals, and more rarely chain corals, cystoid plates, and fragments of brachiopod shells. At top a zone 1 to 5 feet thick shows signs of weathering. Some recrystallization.....	35.0–38.0
	Harding sandstone (Middle Ordovician)	
10	Quartzite, white to dark red brown. A few small typical Harding fish plates, and many weathered pieces of limonite, which suggest replaced and altered fish plates.....	4.0
9	Sandy shale, greenish.....	0.2
8	Quartzite, white, with limonite fragments and stains.....	6.0
	Manitou dolomite (Lower Ordovician)	
7	Dolomite, generally light to dark gray, some light red or purplish pink locally on weathered surfaces; massively bedded, beds 8 inches to 4 feet averaging about 14 inches; fine-grained and compact; traces of crinoid stems and silicified fragments of shells. Some layers show a fibrous structure on weathering suggesting algal limestone. Topographically may form low cliffs.....	78.0
6	Dolomites, light gray; some beds pink or greenish on weathered surfaces; beds 4 inches to 2½ feet averaging about 9 inches; contain chert, but much less than beds below.....	60.0
5	Impure siliceous dolomites, some beds quite sandy; sand grains, some large, are scattered through the dolomite; thin breaks of shale, probably more abundant than appear on outcrops. Dolomite is crystalline. Many beds appear quite porous. White to light gray chert is abundant above lowest 15 or 20 feet. Chert occurs as round or oval concretions, streaks, or as branching tubular masses. Latter are best developed along bedding planes. They suggest replaced fucoid casts. Dolomites are thinly bedded (2 inches to 1½-feet, averaging 4 to 6 inches). Many beds show ripple-marked surfaces.....	74.0
	Sawatch quartzite (Upper Cambrian)	
4	Sandstone, locally a quartzite, white to pink, weathering dark gray or brown; beds thick, averaging about 28 inches; worm borings not uncommon; some layers quite sugary.....	30.0
3	Impure quartzite with interbedded thin impure dolomite, usually white or light gray, thinly bedded; at base is a layer of coarse micaceous sandstone that usually weathers to red brown; other beds are rather fine-grained. small nodules of chert are not uncommon. Streaks and irregular lenses of greenish-gray shale.....	47.0
2	Quartzite, white to light gray weathering to red or yellow tints, fine-grained and compact, massively bedded; hardest part of formation usually a cliff maker, and supplies most of talus on slopes.....	40.0
1	White quartzite conglomerate composed of well-rounded pebbles of white quartz, jasper, and quartz up to about 2 inches across in a matrix of white quartz grains.....	1.8

Unconformity. A slightly irregular surface

Pre-Cambrian gneiss and schist

Section 21.—West Fork Express Creek

Devonian and a part of Mississippian rocks on west fork of Express Creek at lower end of cirque. (Just south of fork of creek.) About west side of sec. 9, 12 S., R. 84 W., Pitkin County, Colorado.

Measured by: J. Harlan Johnson
E. H. Stevens

July 1, 1937

Bed No.	Description	Thickness (feet)
	Leadville limestone (Mississippian)	
	Top of measurable section.	
29	Limestone, dark gray, fossiliferous, (USGS Locality 8460). Yielded specimens of *Syringopora surcularia* Girty, *Craninia* sp. undet., and *Neozophrentis*? sp. undet.....	37.0

Bed No.	Description	Thickness (feet)
28	Covered by talus	24.0
27	Dolomite, dark gray, medium to thick beds	55.0
26	Depositional breccia, grades into dolomite above	5.4
25	Sandstone, brown, medium-grained; fragments of chert and dolomite in basal portion. Rests on a channeled surface with channels 2 to 3 feet wide and 3 to 4 inches deep. Small sandstone dikes extend 3 to 5 inches into dolomite beneath	1.4
	Unconformity	
	Chaffee formation (upper Devonian)	
24	Dolomite, gray, beds medium to massive; many show fine banding or laminations; lenses of depositional breccia near base; some small lenses of chert	16.9
23	Depositional breccia. Subangular pieces of dolomite in a sandy dolomite matrix; fragments in breccia up to 5 by 3 inches	3.0
22	Dolomite, gray-weathering, light-gray beds, 10 to 16 inches thick	8.7
21	Dolomite, gray weathering light gray, fine-textured beds 2 to 6 inches thick, slightly laminated	12.4
20	Depositional breccia. Fragments of blue-gray limestone and light-gray dolomite in a matrix of sand and sandy dolomite	2.6
19	Sandstone, brown, coarse-grained, irregularly silicified; massive beds; suggestions of cross-bedding near base; grades upward into depositional breccia	6.8
18	Depositional breccia. Dolomitic ground mass and fragments; grades into bed below	1.1
17	Limestone, blue gray grading upward into a depositional breccia; irregular channeled surface	3.0
16	Dolomite, light gray, weathers a light brown; beds 4 to 12 inches; vugs and fractures contain small crystals of dolomite; upper layers are granular, crystalline	5.5
15	Dolomite, light gray, weathers light tan; beds 2 to 8 inches	16.4
14	Dolomite, bluish gray, weathering light gray	2.1
13	Dolomite, light gray, fine-grained; beds medium to massive; many beds weather to a fine netted or almost fibrous surface pattern; a few nodules of dark-gray chert	33.5
12	Dolomite, light gray weathering tan; massive beds; fine-grained	11.4
11	Dolomite, dark gray; numerous coarse quartz grains at base, becomes less sandy upward; slabby	5.0
10	Sandstone, very coarse-grained, sand grains up to ¼ inch; weathers dark brown; beds massive; strong cross-bedding; some layers almost a quartzite	16.6
9	Dolomite, impure, dark gray, thin-bedded; streaks and breaks of dark-gray sandy shale. (This layer is soft and is covered in most places.)	13.6
8	Sandy dolomite, gray; coarse sand grains in a fine dolomite	4.5
7	Sandstone, brown, coarse-grained, cross-bedded; ridge-maker	7.8
6	Mudstones, dolomitic, thinly bedded with shale breaks; mottled purple	2.9
5	Mudstones, yellow-tan, somewhat dolomitic; massive beds; weather into irregular nodular forms; breaks of green shale between layers	7.2
4	Sandy dolomite, light yellow with purplish-red spots	2.4
3	Mudstones, very fine-grained, slightly dolomitic, greenish yellow when fresh, light yellow on weathered surface; massive beds, hard and dense	4.6
2	Covered. (*See* Taylor Pass section 10 for details.) Apparently soft slabby sandstone and green shale	23.0
1	Sandstone, brown, medium texture; small lenses of dolomitic sandstone at top	1.6
	Unconformity. Surface irregular. Channels 2½ feet wide and 2 to 3 inches deep	
	Manitou dolomite and older beds. (*See* Taylor Pass section 10.) This was measured across cirque about ½ mile to WNW.	

Section 22.—Express Mine

Leadville and upper part of Chaffee formations, just north of old Express Mine on Express Creek, one mile south of Ashcroaft about sec. 32, T. 11 S., R. 84 W., Pitkin County, Colorado.

Measured by: J. H. Johnson — June 30, 1937
E. H. Stevens — July 1, 1937

Bed No.	Description	Thickness (feet)
	Weber (?) *formation* (Pennsylvanian)	
	Unconformity: contact covered on surface, but as exposed in a near-by pit it appears as a nearly horizontal surface. Upper layers of Leadville show weathering and solution effects.	
	Leadville limestone (Mississippian)	
38	Limestone, blue gray on weathered surface, dark gray when fresh; massive beds; contains corals, crinoid stems, fragments of brachiopods, and probably Foraminifera. Following species were obtained: *Syringopora harveyi* White and *Caninia* sp. undet.	8.0
37	Limestone, dark-gray, massive beds; contains same fossils as beds above, also fine-grained concentric masses and crusts around corals that suggest growths of calcareous algae. Yielded *Syringopora harveyi* White and *Caninia* sp. undet.	10.0
36	Limestone, gray, medium-bedded. Rock has a granular texture as a result of much organic debris—crinoid stems, dark algal, pellets, horn corals up to 3 inches long, a few conical gastropods, heads of *Syringopora* up to 8 inches in diameter. Recrystallization prevented identification of horn corals. Gastropod was identified as *Straparolus ophirensis* (Hall and Whitfield)	4.0
35	Limestone, dark gray to black; has a slight bituminous odor on breaking	17.0
34	Dolomite, gray, weathering brown; beds 4 inches to 1 foot thick	14.5
33	Limestone, dark gray; massive beds (up to 4); contains corals and much fragmental organic material	21.4
32	Porous limestone, dark gray, weathers brownish; contains well-developed dark algal growths, crinoid stems, and organic debris	13.2
31	Dolomite and limestone. Lenses of dolomite up to 3 feet thick and 18 ft. long	7.0
30	Limestone, dark gray; contains many horn corals, belonging to genera *Homalophyllum?* and *Caninia*	2.5
29	Dolomite, dark gray, weathers brown; beds 4 to 10 inches	4.6
28	Limestone, dark gray	3.9
27	Dolomite, gray, weathering brownish, thinly bedded	6.4
26	Limestone, dark gray, massive beds	18.3
25	Limestone with thin irregular streaks of dolomite	4.5
24	Dolomite, gray, weathering brownish. Vugs are coated with small dolomite crystals that have larger calcite crystals on them	11.0
23	Limestone, gray, weathering light gray; a few chert nodules, chert well developed along the lower contact, which is wavy	4.3
22	Dolomite, dark gray, beds medium, some dark chert in dolomite; some chert pieces are fractured and displaced without similar displacements being apparent in dolomite	19.4
21	Dolomite, gray weathering light; beds medium (8 inches) to massive; blends into material beneath without sharp demarcation; a few dark chert masses	9.0
20	Dolomite, depositional breccia. Fragments of dolomite, limestone, and chert, slightly rounded, in a groundmass of sandy dolomite and (at base) sand; sand grains medium to coarse; fragments in breccia up to 5 inches long and 2 inches thick; fragments of quartzite (1.5 by 5 inches)	3.4
19	Sandstone, brown, cross-bedded, coarse-grained; also sandy depositional breccia	4.2
	(Total thickness Leadville)	186.6
	Unconformity. Surface only slightly wavy	
	Chaffee formation (Devonian)	
18	Dolomite, gray, weathering light gray; beds 4 to 12 inches thick; some beds finely laminated	11.4
17	Limestone, slightly dolomitic, dark gray, almost black (one layer)	1.3
16	Limestone, dark gray, almost black	1.1
15	Dolomite, light gray, laminated	4.8
14	Limestone, dark gray	0.8
13	Dolomite, light gray, laminated	1.1
12	Limestone, dark gray, slabby	1.7
11	Dolomite, light gray, laminated	2.9
10	Dolomite, dark gray, massive	1.4
9	Limestone, almost black	2.2
8	Dolomite, light gray, beds 4 to 8 inches thick; weathers to light yellow gray	14.3

Bed No.	Description	Thickness (feet)
7	Dolomitic limestone, slightly shaly	2.4
6	Dolomite, light gray, beds 6 to 14 inches; thin shale breaks between layers; weathers to light yellow; contains streaks of depositional breccia	4.7
5	Sandstone, brown, coarse-grained, almost a quartzite	1.2
4	Dolomitic limestone, dark gray, quite sandy, massively bedded; depositional breccia at top	3.7
3	Dolomite, light gray	0.6
2	Sandstone, brown	0.8
1	Dolomite, light gray, thin-bedded	3.0
	Base covered by talus and glacial drift.	
	Total Chaffee measured	59.4

Section 23.—Meredith Quarry

Old quarry about ¼ mile south of Meredith in sec. 14, T. 8 S., R. 83 W., Pitkin County, Colorado.

Measured by: J. H. Johnson, H. Mendenhall — July 28, 1937

Bed No.	Description	Thickness (feet)
	Weber (?) *formation* (Pennsylvanian)	
	Outcrops on flats to north.	
	Unconformity. (Contact covered by terrace gravels)	
	Leadville limestone (Mississippian)	
	A little of top of formation may have been removed by erosion at end of quarry, but only a few feet at most.	
5	Limestone, dark gray with streaks of lighter, highly organic limestone; beds massive. Some oölitic material near top contains abundant Foraminifera identified as *Endothyra baileyi* (Hall) and *Endothyra* sp. undescribed. Gray limestone 8 feet below top. All beds contain abundant fragments of organic material. A few large gastropods (*Straparolus* (*Euomphalus*) *utahensis* Hall and Whitfield?) near base	14.0
4	Limestone, dark gray, massive, similar to that above; contains large horn corals, *Syringopora*, and large gastropods; streaks and lenses of foraminiferal-algal limestone	17.8
3	Band of breccia composed of fragments of limestone and dolomite in a dolomitic matrix on a slightly wavy bedding plane. (Conspicuous band about halfway down face of quarry.)	0.6
2	Limestone, dark gray, massive, similar to above limestone; pronounced bedding plane at base	9.2
1	Limestone, dark gray, massive, similar to above	26.4
	Base exposed in quarry; lower beds occur in gulch above.	

Section 24.—Frying Pan River, Mouth of Lime Creek

On north side river at mouth of Lime Creek in sec. 19, T. 8 S., R. 83 W. Pitkin County, Colorado.

Measured by: J. Harlan Johnson, H. Mendenhall — July 28, 1937

Bed No.	Description	Thickness (feet)
	Leadville limestone (Mississippian)	
	Cut by fault. Material above fractured, and stratigraphic position uncertain.	
11	Limestone, dark gray, very massive; contains a few fragments of crinoid stems and a few large gastropods; a cliff-making member	40.0
10	Limestone, gray to dark gray; contains abundant fragments of crinoid stems and other organic debris; finely oölitic at top	8.0
9	Limestone, light gray with irregular streaks of chalky material; crinoid stems abundant, a few small gastropods	11.4
8	Limestone, hard and dense, dark gray with lenses and streaks of light-gray (almost white) highly organic limestone, apparently composed largely of Foraminifera, horn corals, algal colonies, and crinoid stems	5.7
7	Limestone, dark blue gray, almost black when fresh; very massive beds; grades up into material above without break	22.0

Bed No.	Description	Thickness (feet)
6	Dolomite, light gray, massive, angular fracture. This bed lenses into limestone to southwest	3.7
5	Limestone, dark blue gray, massive	8.2
4	Dolomites and dolomitic limestone; bedding medium to massive	27.3
3	Dolomites and highly dolomitic limestones, dark gray; beds 3 to 8 inches thick	15.0
2	Sandstone, light brown, grading upward into a coarse depositional breccia composed of lime, dolomite, and chert fragments in a matrix of sand; fragments up to 8 inches long, 4 inches wide, and 3 inches thick; majority are angular and show little wear; sand grains coarse; a few small quartz pebbles	7.0
	Total Leadville	148.3
	Unconformity. Surface only slightly wavy	
	Chaffee formation (Devonian)	
1	Dolomite, gray, weathering light gray; beds 3 to 7 inches thick; some layers banded; others dark gray, almost black. Lower beds not exposed	39.0

Section 25.—Lime Creek

Partial section of Leadville limestone measured on cliff at junction of Lime and Little Lime Creeks below Woods' Lake, about S.W. cor. sec. 28, T. 7 S., R. 83 W., Eagle County, Colorado.

Measured by: J. H. Johnson
E. H. Stevens
July 15, 1937

Bed No.	Description	Thickness (feet)
11	*Weber (?) formation* (Pennsylvanian) Some thin limestones. Black chert pieces, some with brachiopods and fossil wood.	
	Unconformity	
	Leadville limestone (Mississippian)	
10	Limestone, dark blue-gray, bedding massive. At top, material is locally almost an algal pisolite. Fossiliferous, yielded following forms: *Syringopora surcularia* Girty, *Canania* sp. undet., *Homalophyllum* sp. A., *Amplexus?* sp. undet., *Composita humilis* Girty, *Loxonema?* sp. undet., *Straparolus ophirensis* (Hall and Whitfield) *Straparolus* (*Euomphalus*) cf. *S. blairi* Miller, *Straparolus* (*Euomphalus*) cf. *S. luxus* (White), "*Orthoceras*" sp. undet., *Schizodus* aff. *S. palaeoneiliformis* Herrick	5.0
9	Limestone, blue gray, massive; caps cliff; contains a few corals and gastropods and much organic debris	22.0
8	Limestone, blue gray, similar to bed above	3.6
7	Limestone, dark gray, contains numerous irregular masses of dark-gray chert; lower surface wavy	0.7
6	Limestone, dark gray, crystalline, massive	6.0
5	Limestone, dark gray, extremely massive; cliff-maker; no definite bedding; many crinoid stems, some corals and Bryozoa	34.8
4	Dolomite, layer composed of angular and nodular pieces, mainly of dolomite, a few of chert or limestone; weathers like concrete; a fairly definite horizon marker on cliff face	0.9
3	Limestone, dark blue, with band that looks like foraminiferal limestone at base	14.0
2	Limestone, dark gray, massive	16.2
1	Limestone, dark gray to black, very massive Bottom of cliff. Balance of formation not exposed. Tracing beds along cliff for about half a mile, basal sandstone of Leadville outcrops about 40 feet below lowest bed of section.	32.5

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